Next generation *g – 2* experiment at Fermilab

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for *g – 2* collaboration

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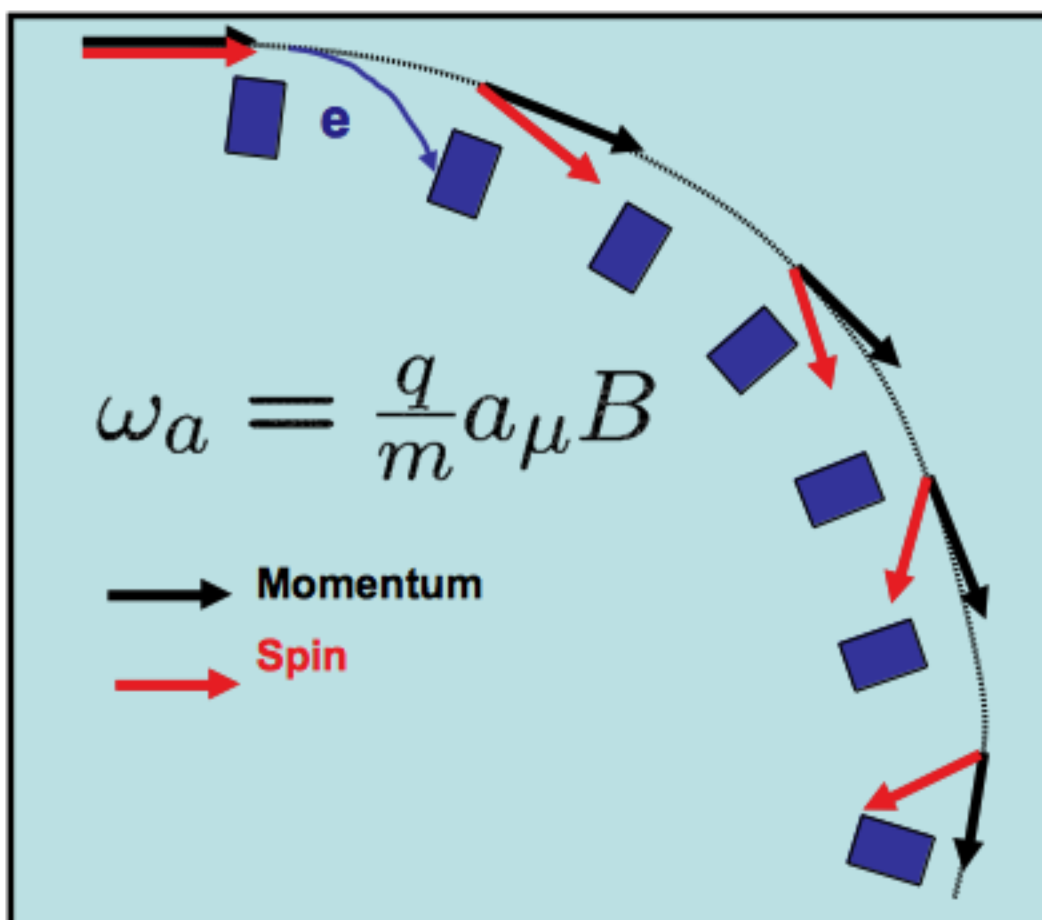
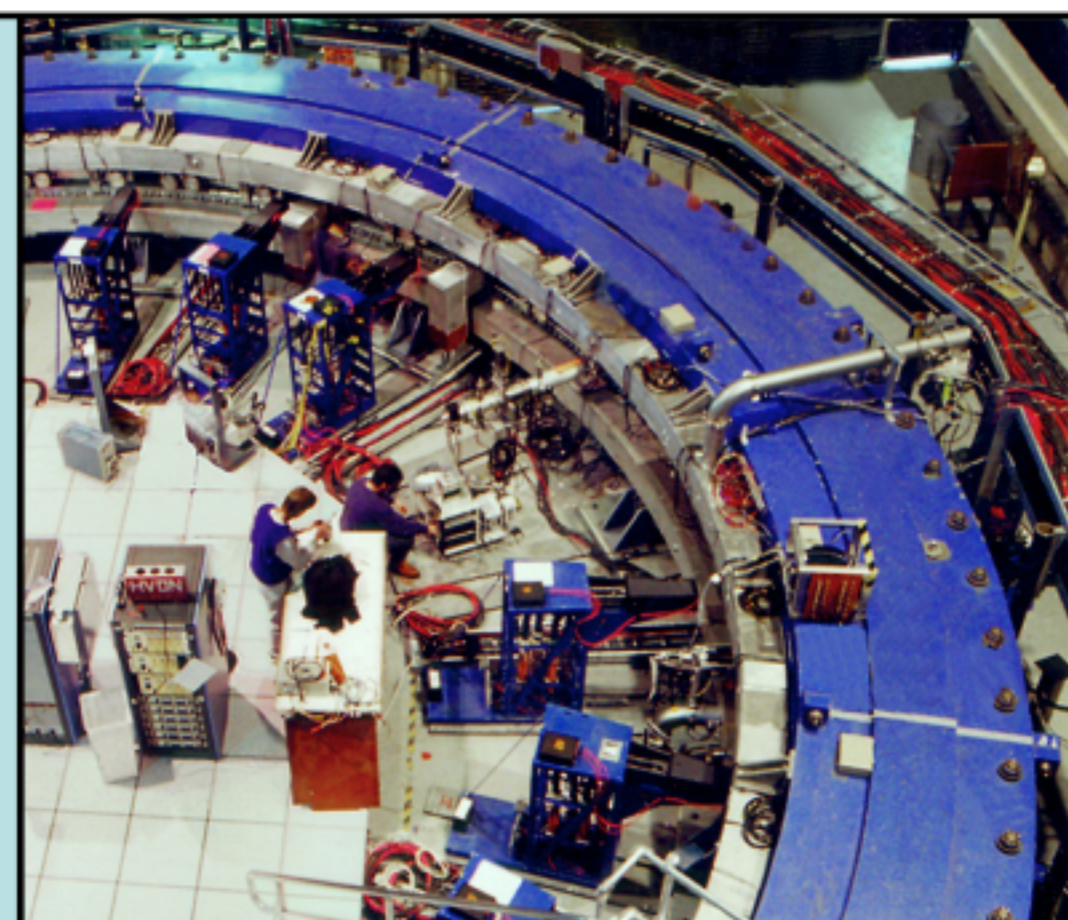
magnetic dipole moment of muon

torque experienced in external magnetic field,
spin -> intrinsic magnetic dipole moment,
experiment measures how fast spin rotates

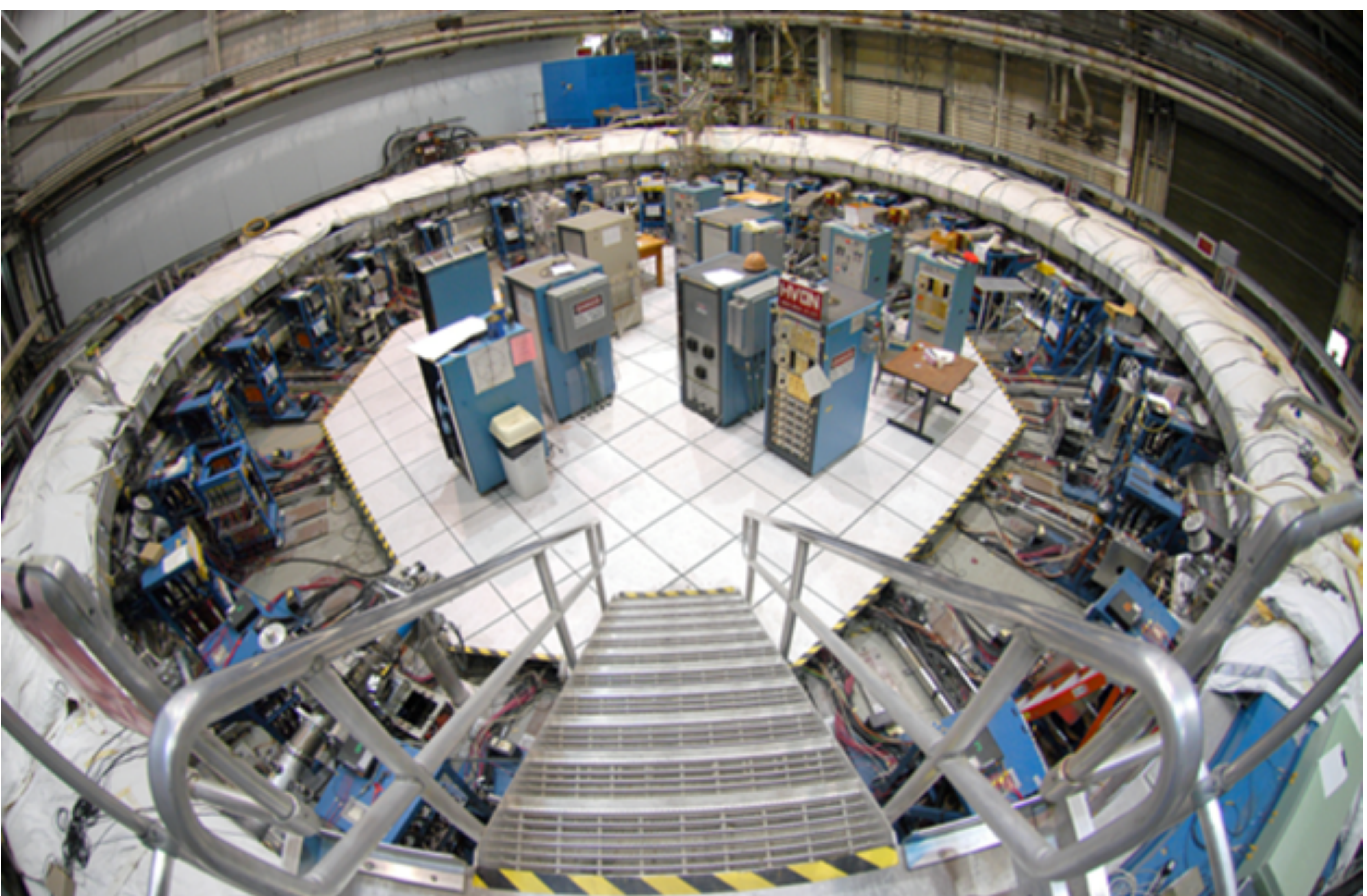




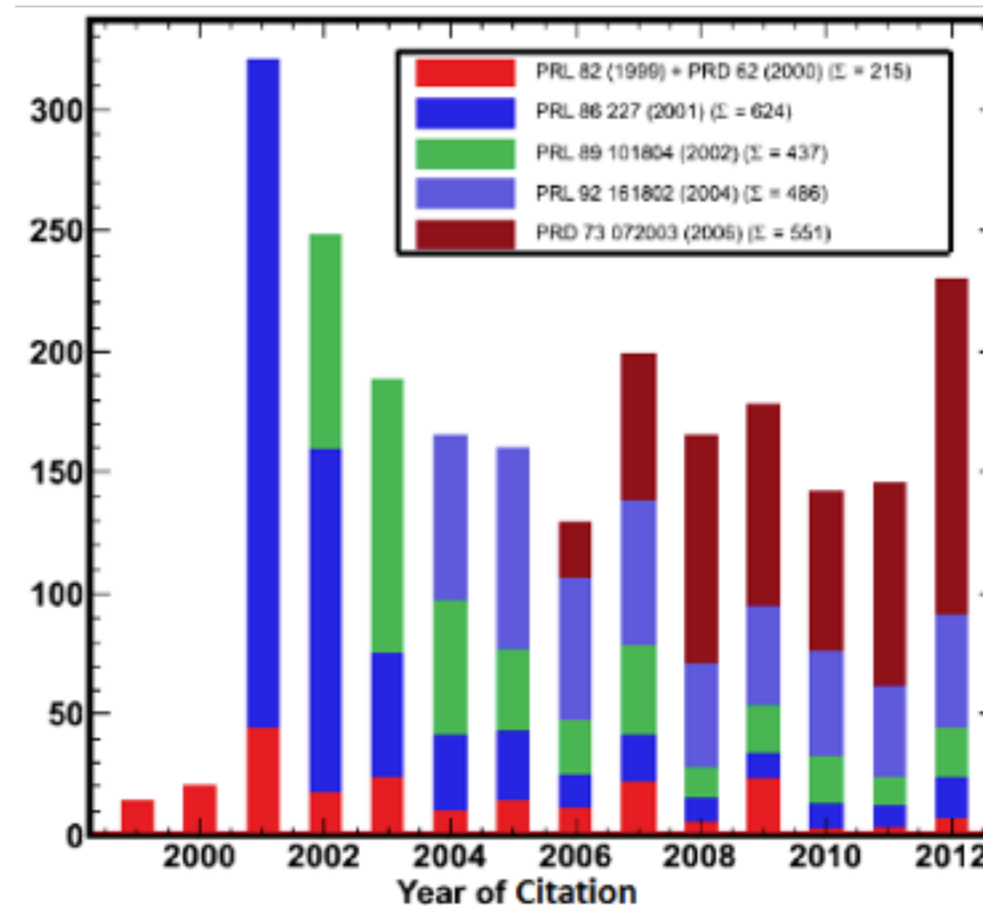
g – 2 experiment at BNL

E821 (1999 - 2006):
a_μ = 0.001 165 920 89 (63) (±0.54 ppm)

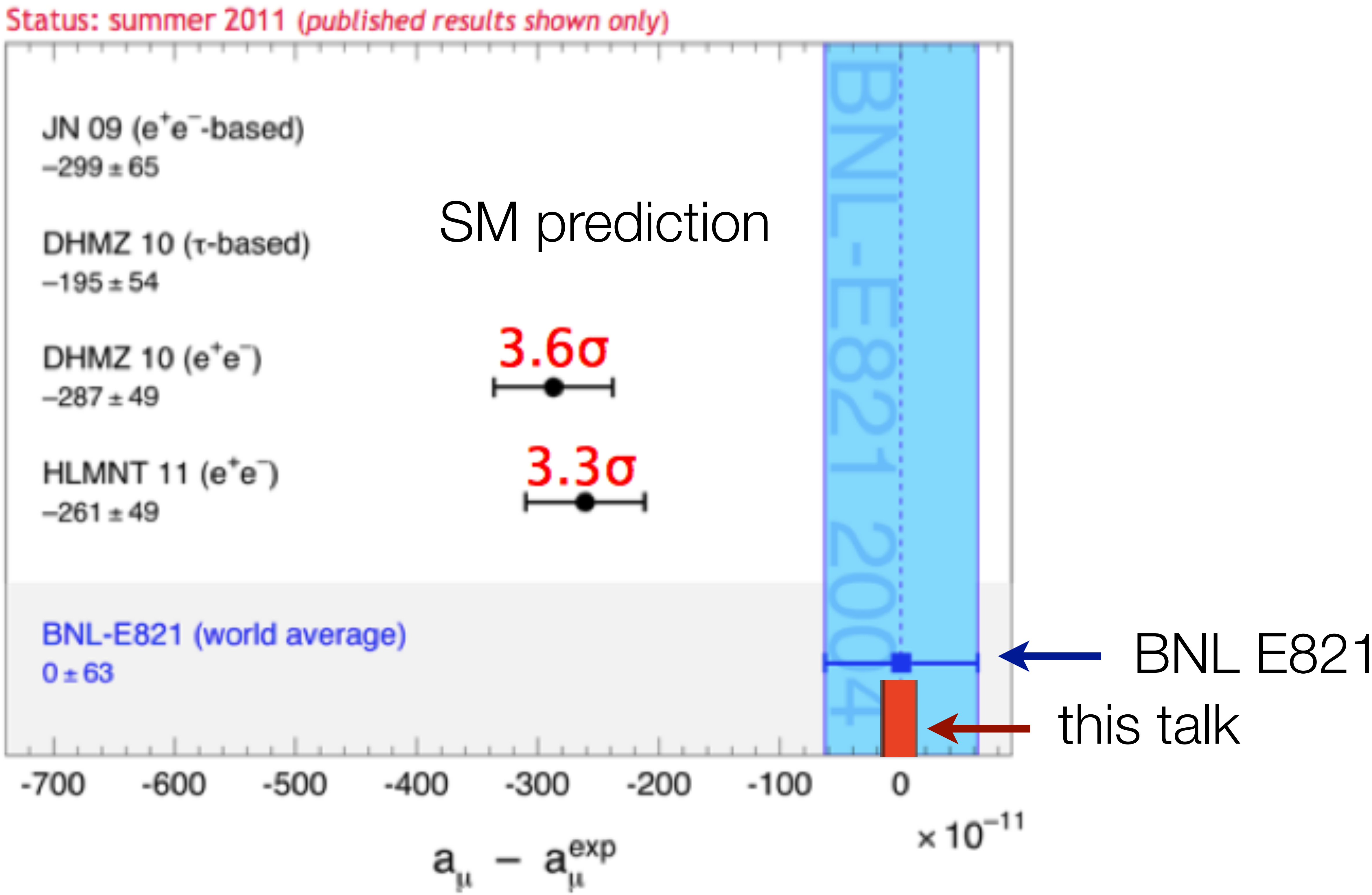
Figure 1.10: A picture from 1984 showing the attendees of the first collaboration meeting to develop the BNL g-2 experiment. Standing from left: Gordon Danby, John Field, Francis Farley, Emilio Picasso, and Frank Krienen. Kneeling from left: John Bailey, Vernon Hughes and Fred Combley.



A highly cited result



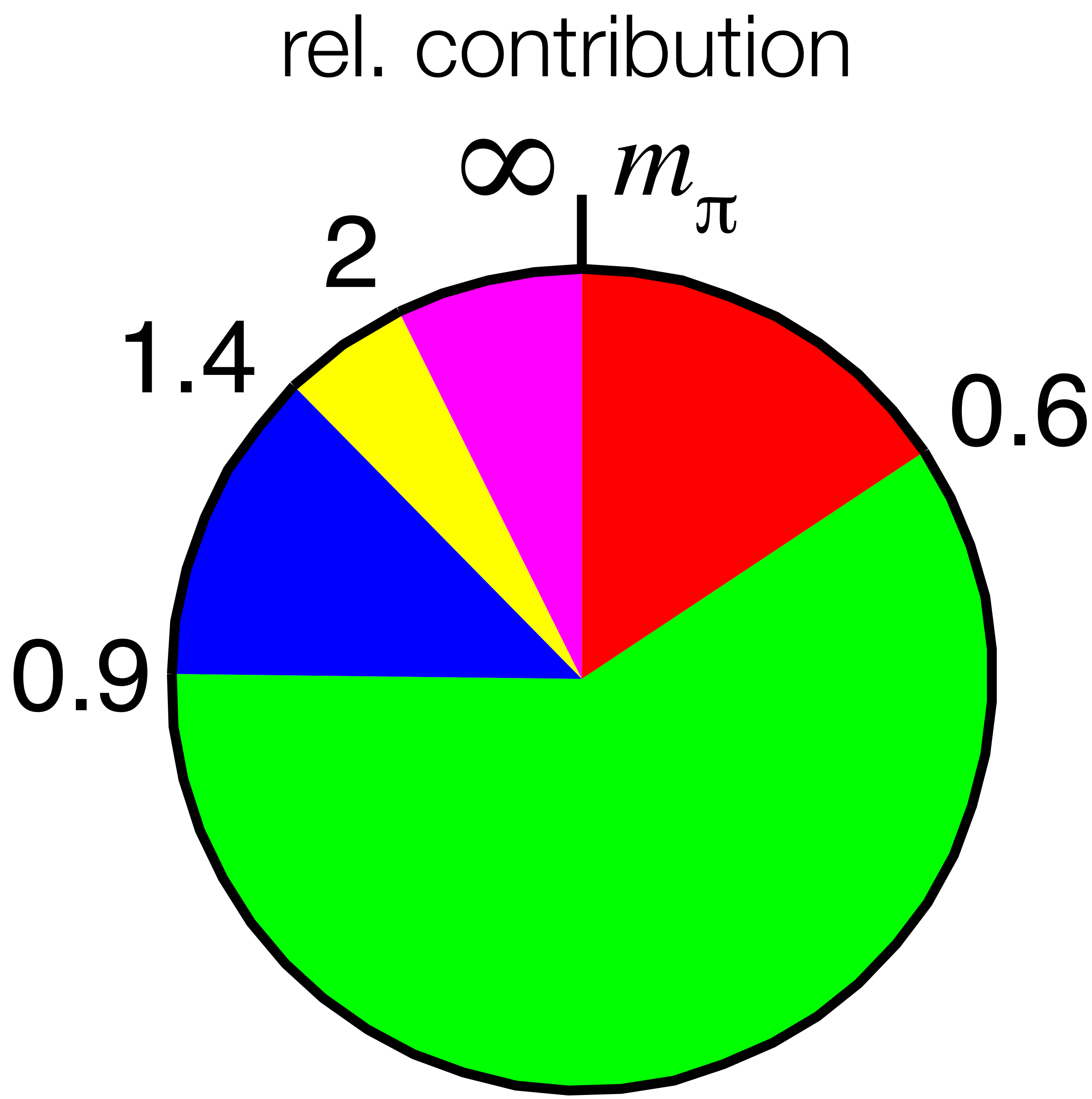
Standard Model prediction

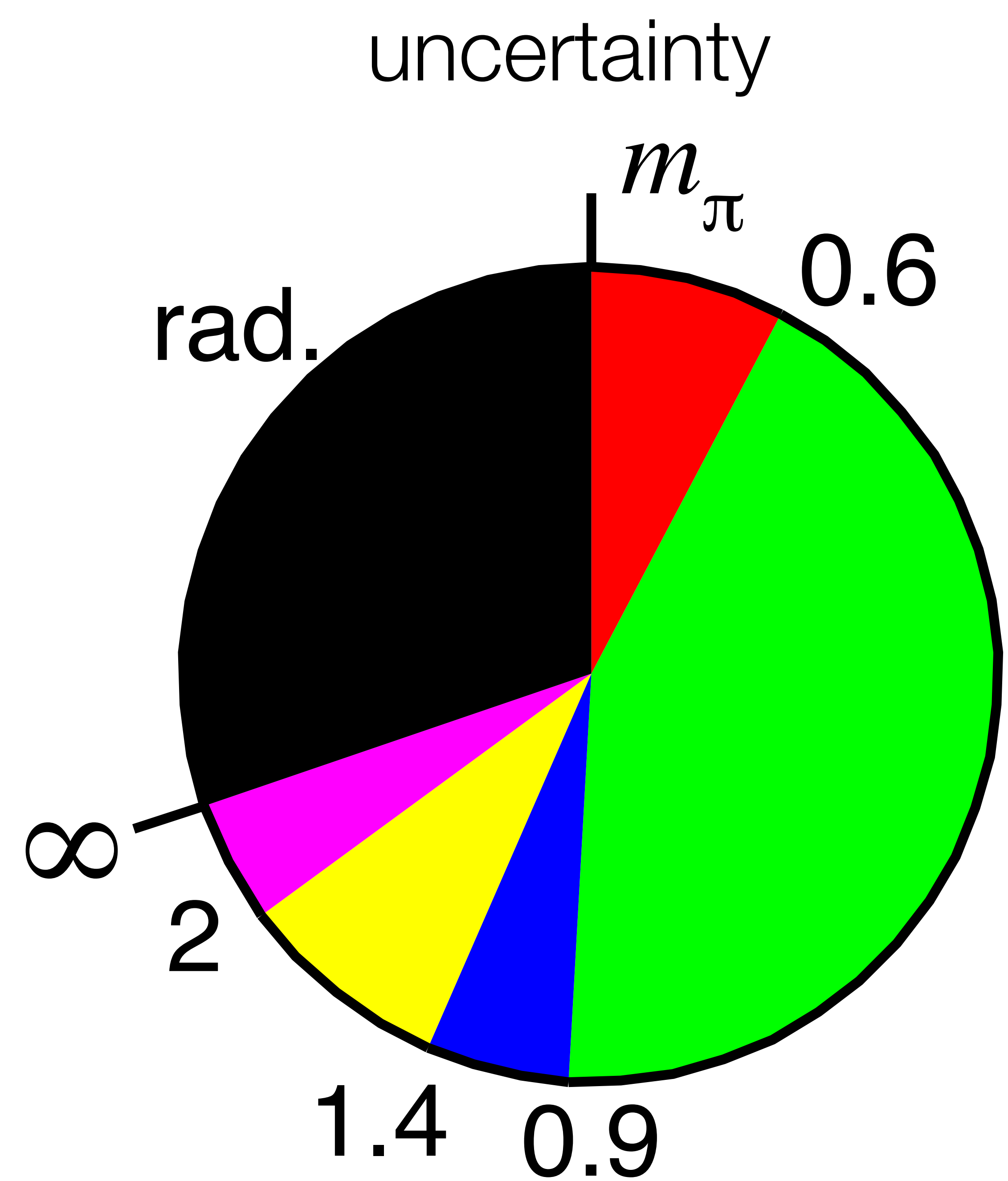


SM contributions

	Value ($\times 10^{-11}$) units
QED ($\gamma + \ell$)	$116\,584\,718.853 \pm 0.022 \pm 0.029_{\alpha}$
HVP(lo)*	$6\,923 \pm 42$
HVP(ho)	-98.4 ± 0.7
H-LBL	105 ± 26
EW	$154 \pm 1 \pm 2$
Total SM	$116\,591\,802 \pm 42_{\text{H-LO}} \pm 26_{\text{H-HO}} \pm 2_{\text{other}}\ (\pm 49_{\text{tot}})$

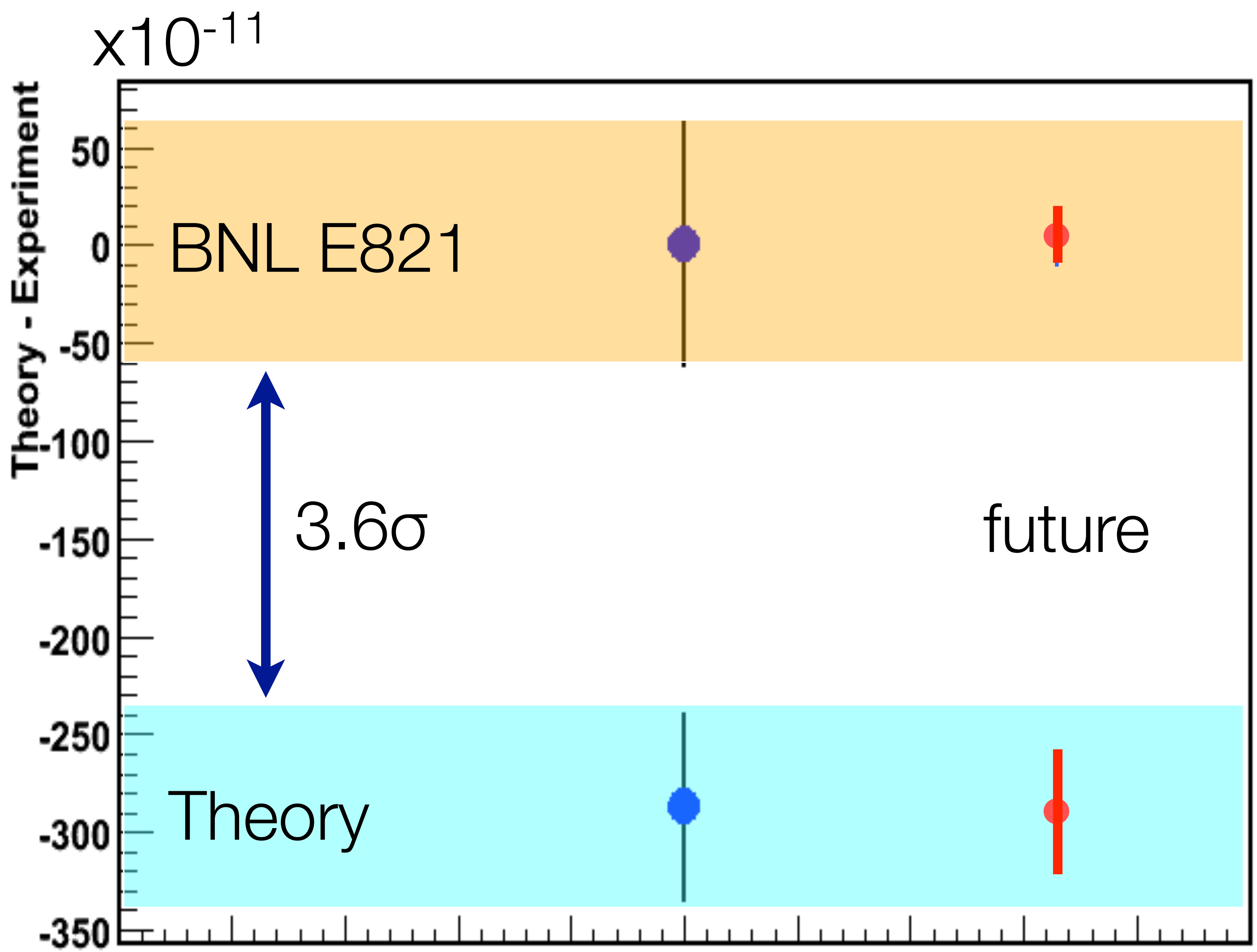
SM had. vacuum polarization





arxiv:1105.3149v2

BNL E821 statistically limited



goal: 0.14 ppm
20x data

7.5σ if same
central values

expected
improvement

E989: 38 institutes, >150 members

- Domestic Universities
  - Boston
  - Cornell
  - Illinois
  - James Madison
  - Massachusetts
  - Mississippi
  - Kentucky
  - Michigan
  - Michigan State
  - Mississippi
  - Northern Illinois University
  - Northwestern
  - Regis
  - Virginia
  - Washington
  - York College
- National Labs
  - Argonne
  - Brookhaven
  - Fermilab
- Consultants
  - Muons, Inc.

Italy
- Frascati,
- Roma 2,
- Udine
- Pisa
- Naples
- Trieste

China:
- Shanghai

The Netherlands:
- Groningen

Germany:
- Dresden

Japan:
- Osaka

Russia:
- Dubna
- PNPI
- Novosibirsk

UK

University College London
Liverpool
Oxford
Rutherford Lab

Korea

KAIST

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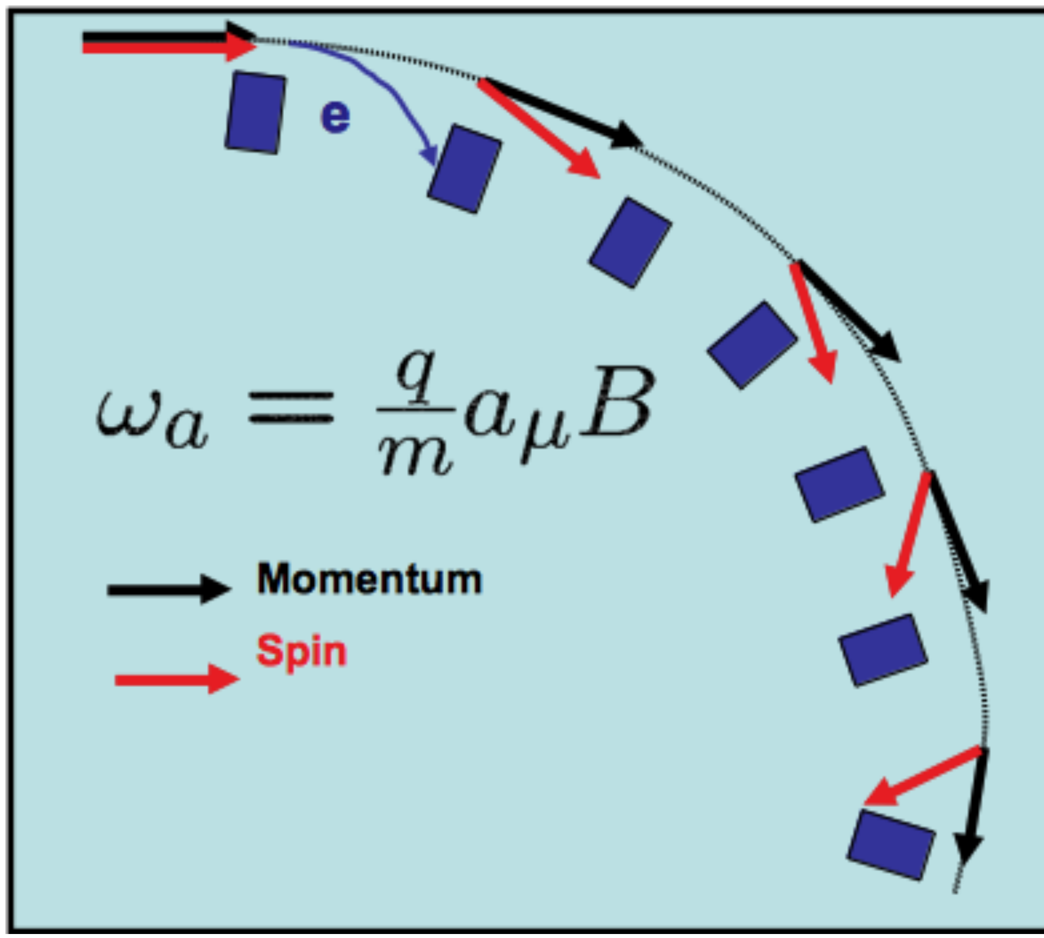
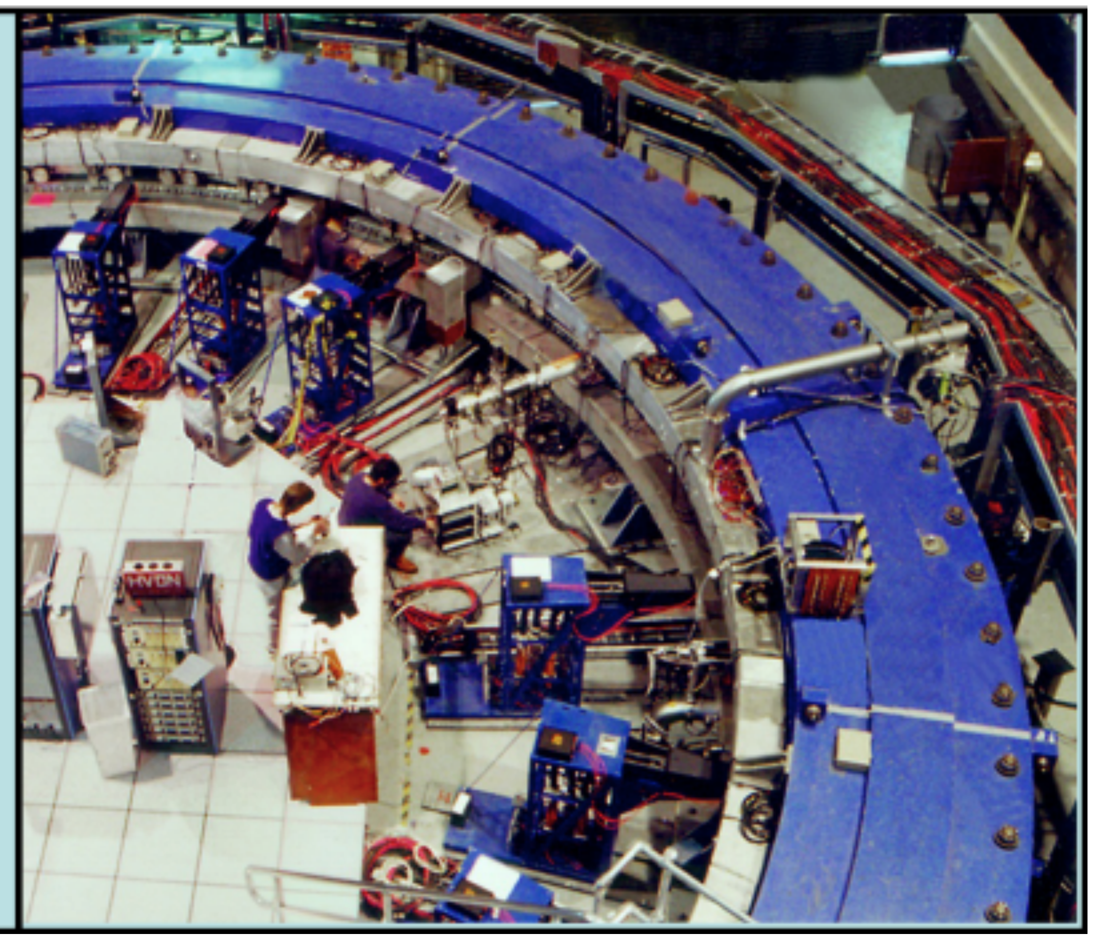
B.L. Roberts, Co-Spokesperson, roberts@bu.edu
C. Polly, Project Manager

principles of the experiment





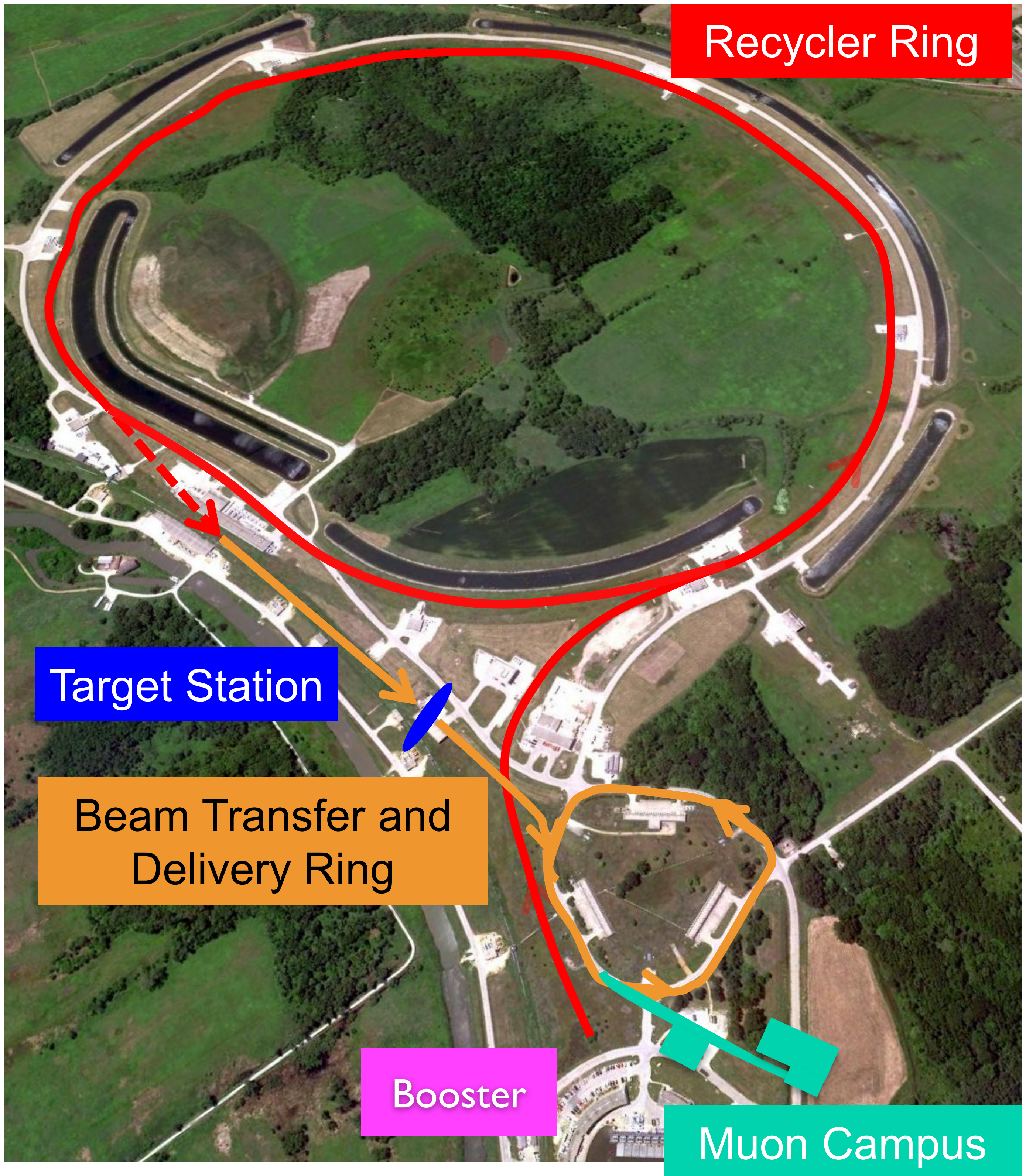
principles of the experiment

1. source of polarized muons (0.95 polarization)
2. precession proportional to *(g – 2)*
3. magic momentum
4. parity violating decay (positron reports on spin)

1. source of polarized muons

- pion decay into muon
- it's parity violating decay
- spin prefers opposite direction to momentum
  (for positive pion)
- pions come from protons hitting Li target

1. source of polarized muons

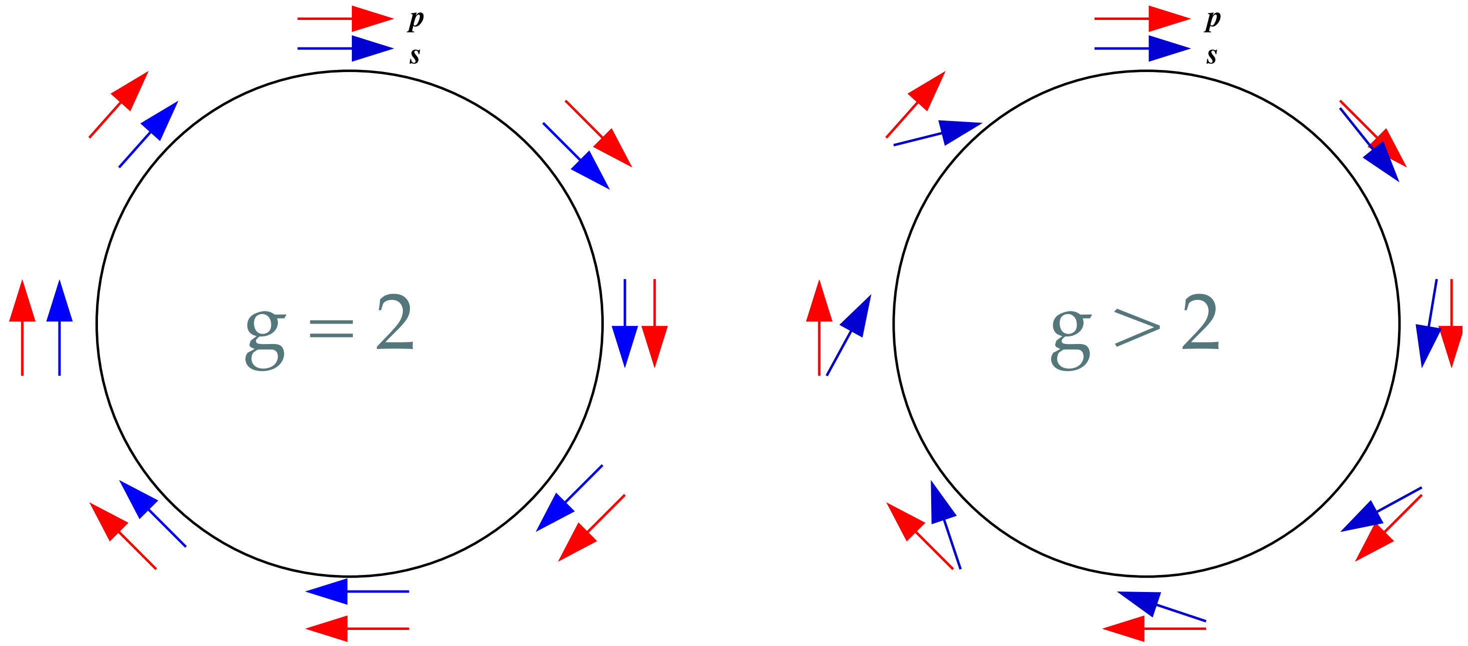


- Recycler
  - 8 GeV protons from Booster
  - Re-bunched in Recycler
  - New connection from Recycler to P1 line (existing connection is from Main Injector)
- Target station
  - Target
  - Focusing (lens)
  - Selection of magic momentum
- Beamlines / Delivery Ring
  - P1 to P2 to M1 line to target
  - Target to M2 to M3 to Delivery Ring
  - Proton removal
  - Extraction line (M4) to g-2 stub to ring in MC1 building

2. precession proportional to $g - 2$

$$\omega_C = \frac{eB}{mc\gamma} \qquad \omega_S = \frac{geB}{2mc} + (1-\gamma)\frac{eB}{\gamma mc}$$

$$\omega_a = \omega_S - \omega_C = \left(\frac{g-2}{2}\right)\frac{eB}{mc} = a\frac{eB}{mc}$$



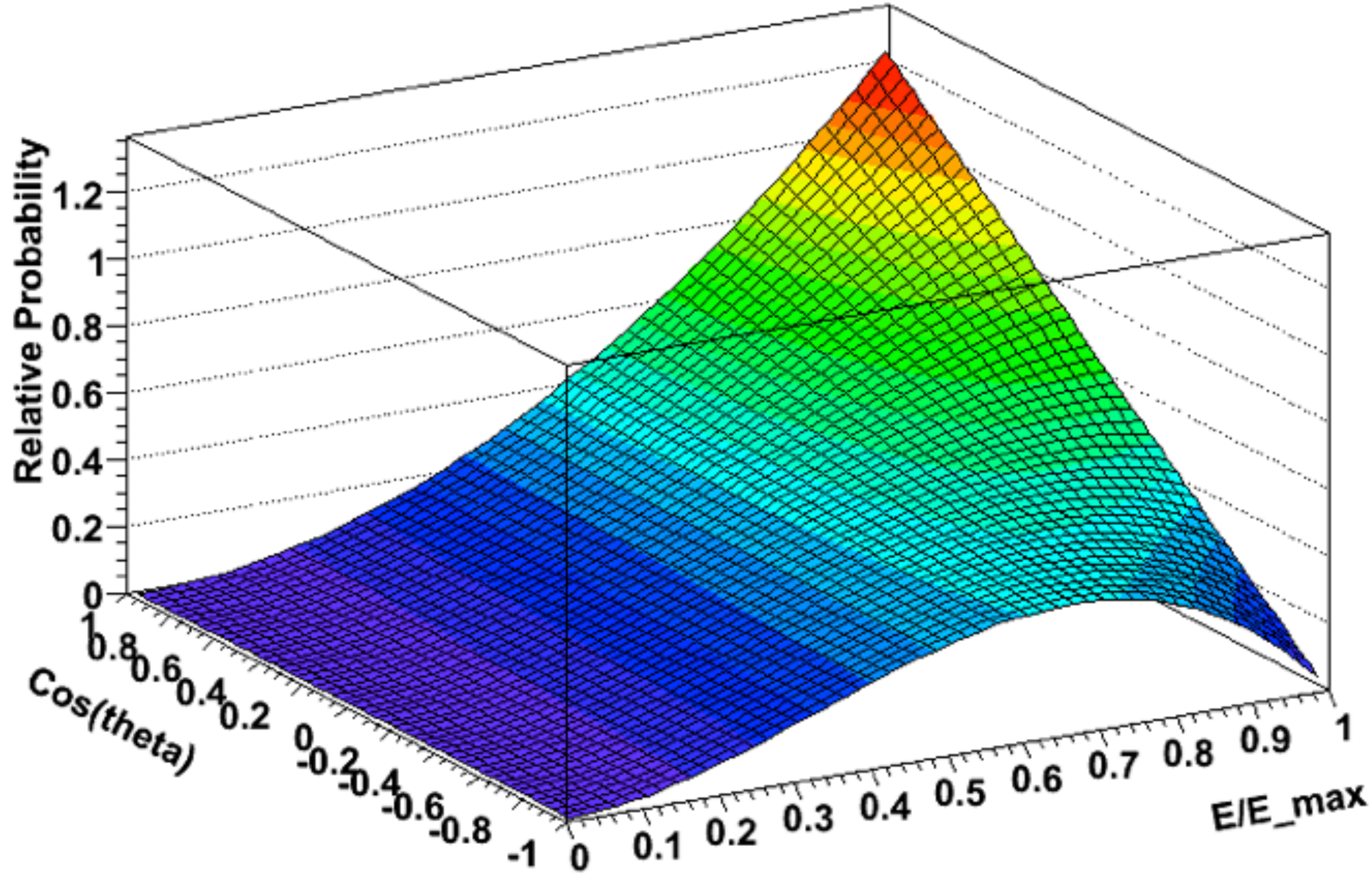
3. magic momentum

- electric quadrupole used for vertical focusing

$$\vec{\omega}_a = -\frac{e}{m}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta} \times \vec{E}}{c}\right]$$

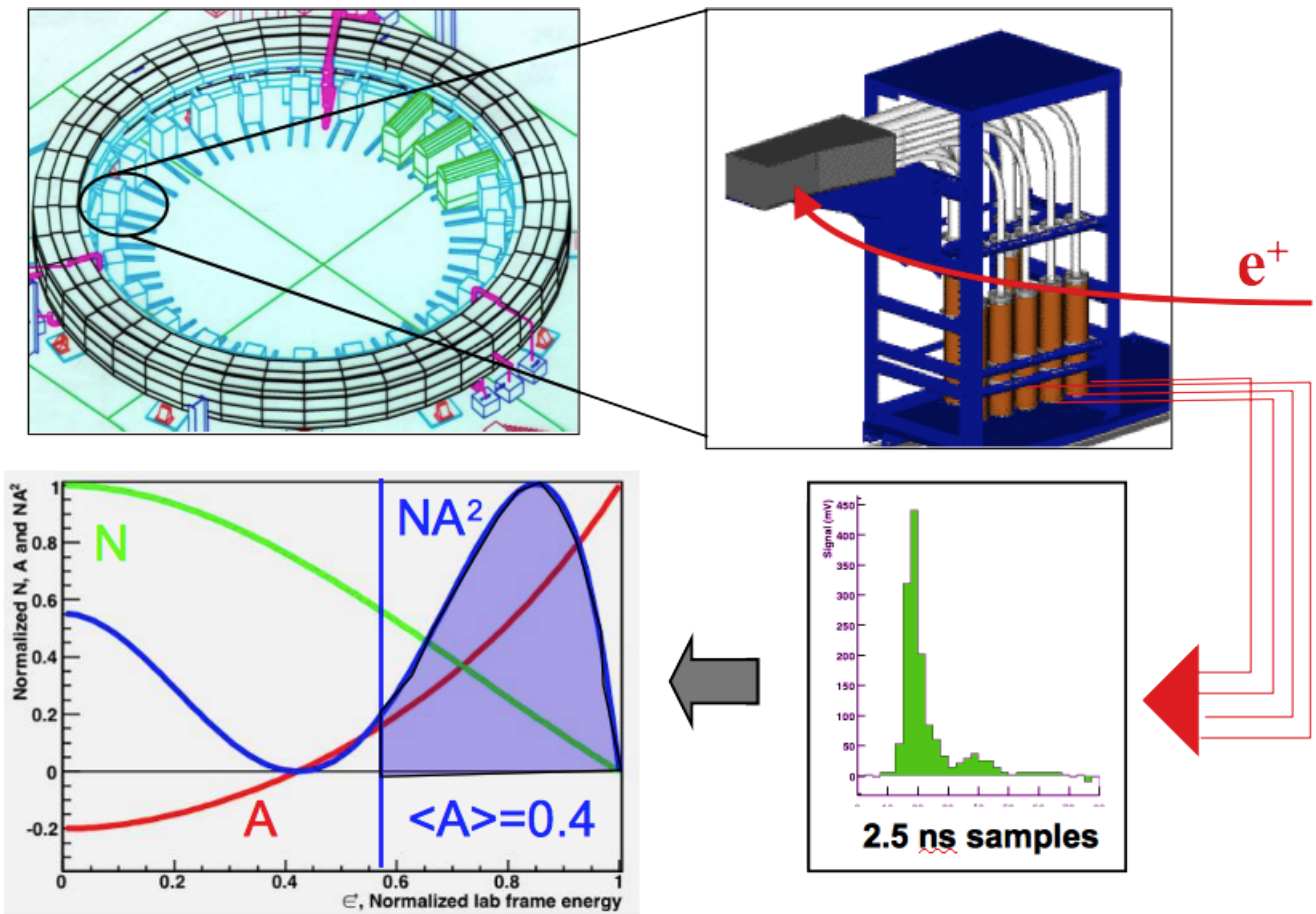
- select $\gamma = 29.3$, muon momentum 3.094 GeV

4. parity violating decay

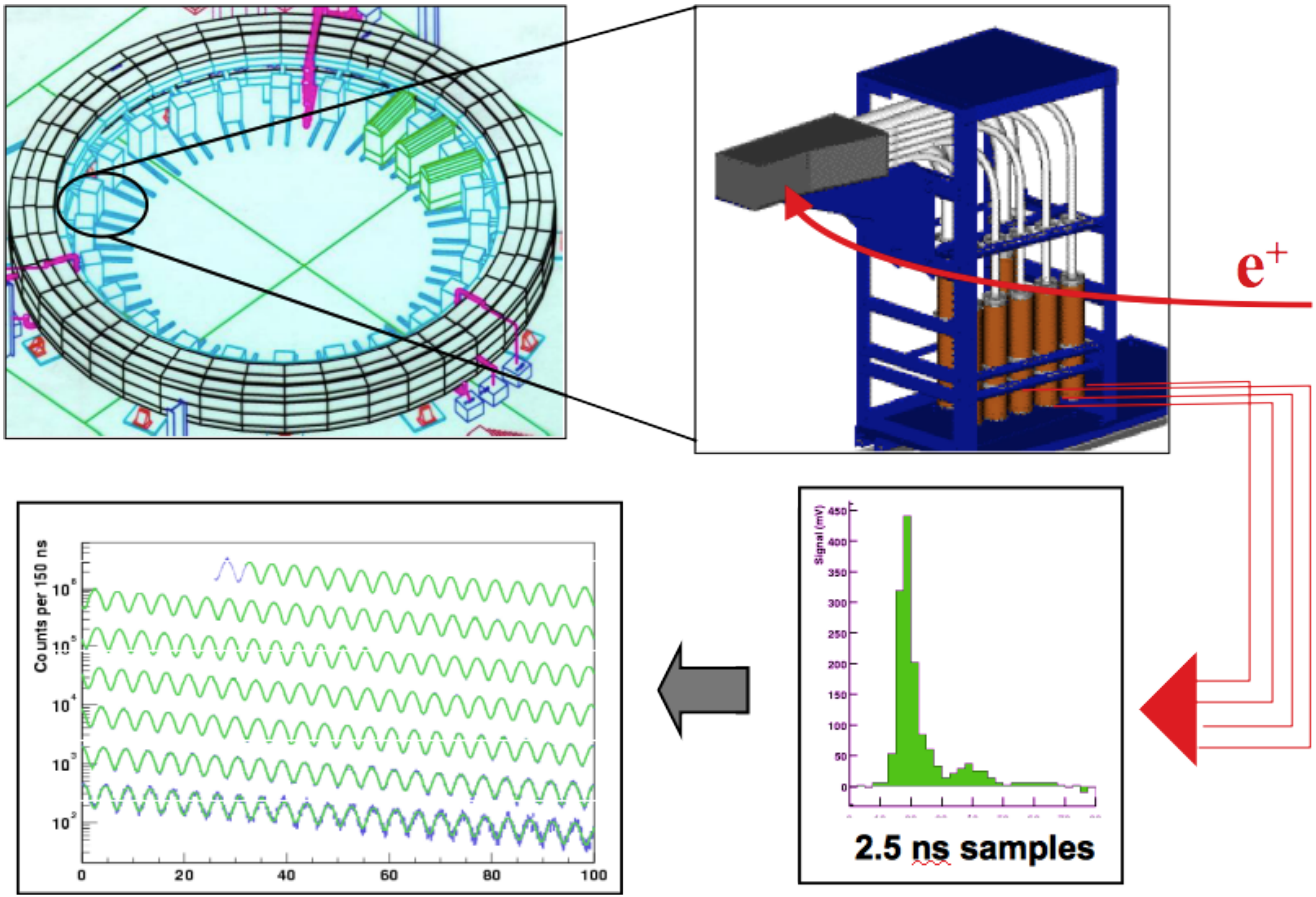


- muon -> electron and two neutrinos
- electron carries information on muon’s spin
- positron prefers spin direction
- electron would prefer opposite direction

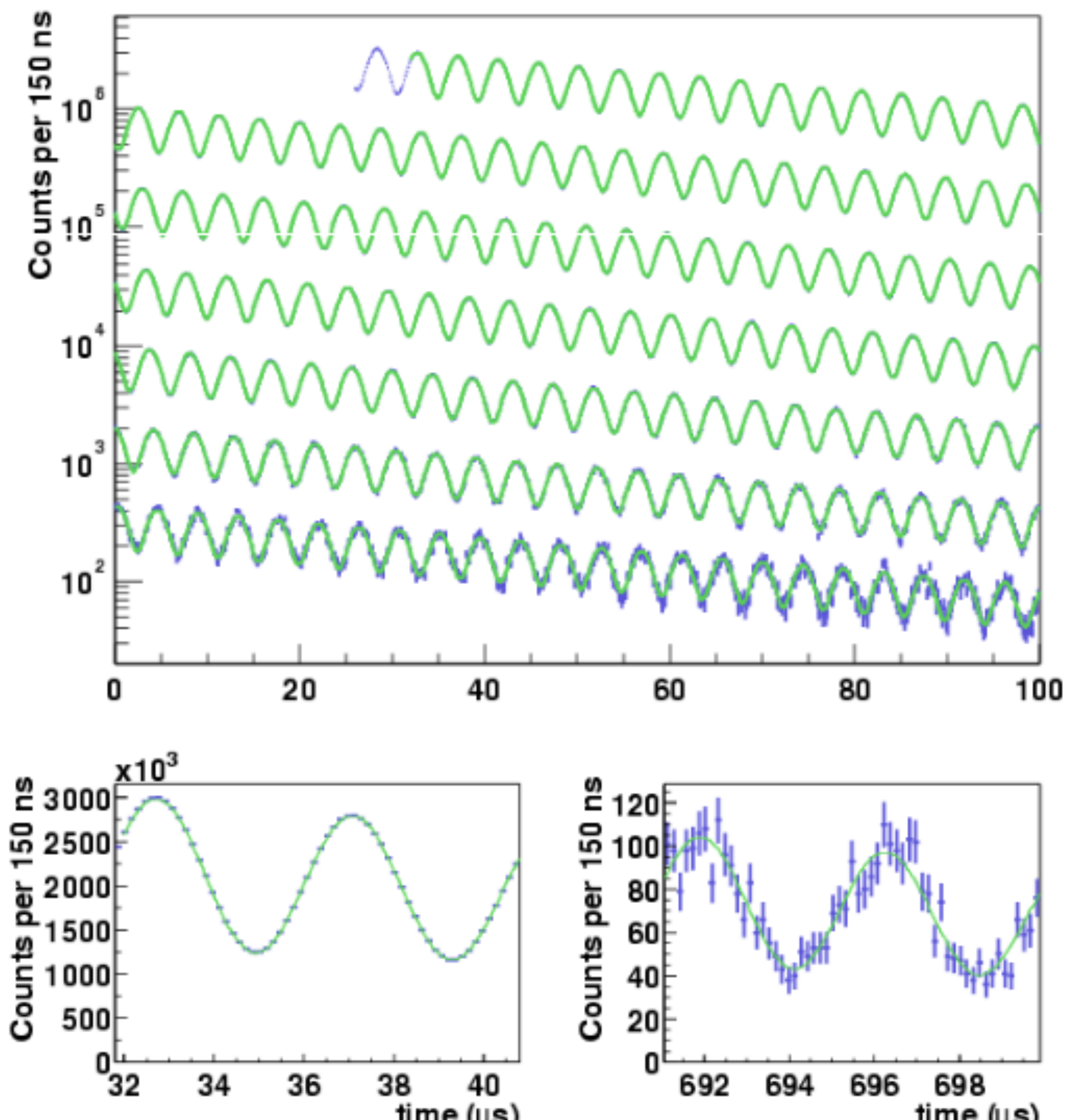
single event



collect billions of events

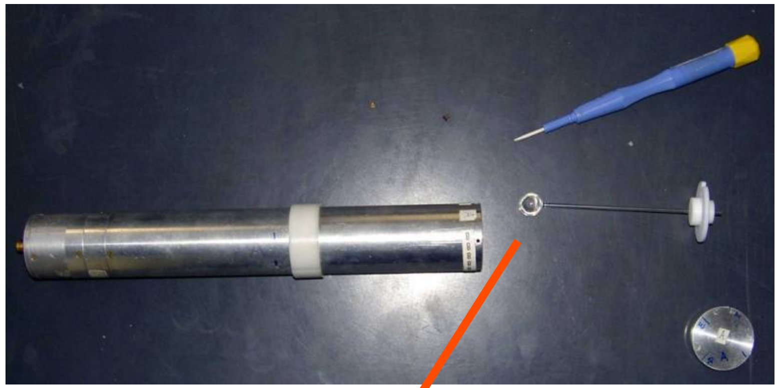


extract frequency ω_a

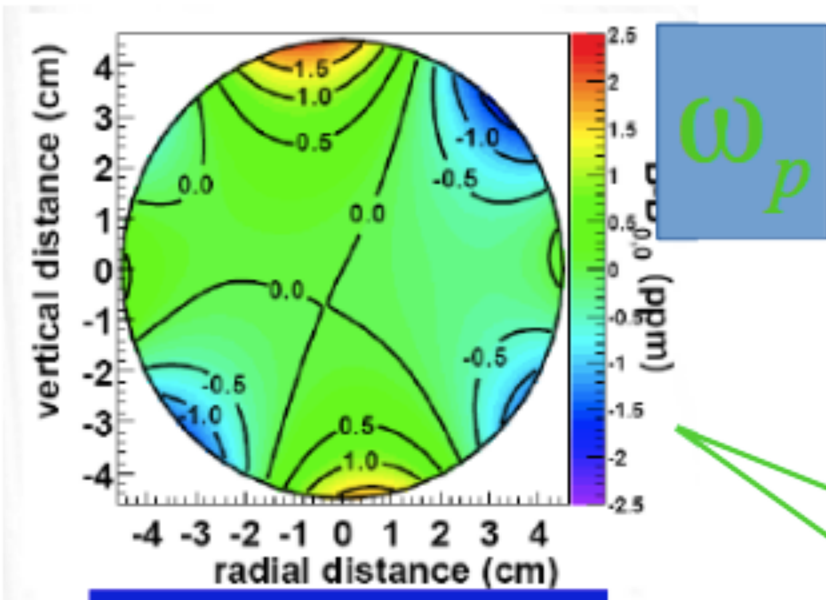


measure magnetic field

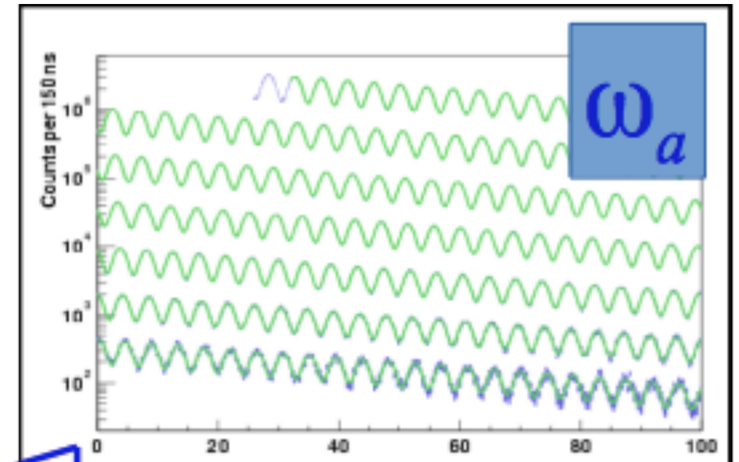
- pulsed NMR with free induction decay
- to measure Larmor frequency of proton ω_p
- in the same magnetic field B



combine together

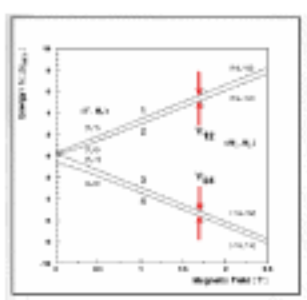


Our "Magnet"



Our conventional Detector, Electronics, and DAQ systems

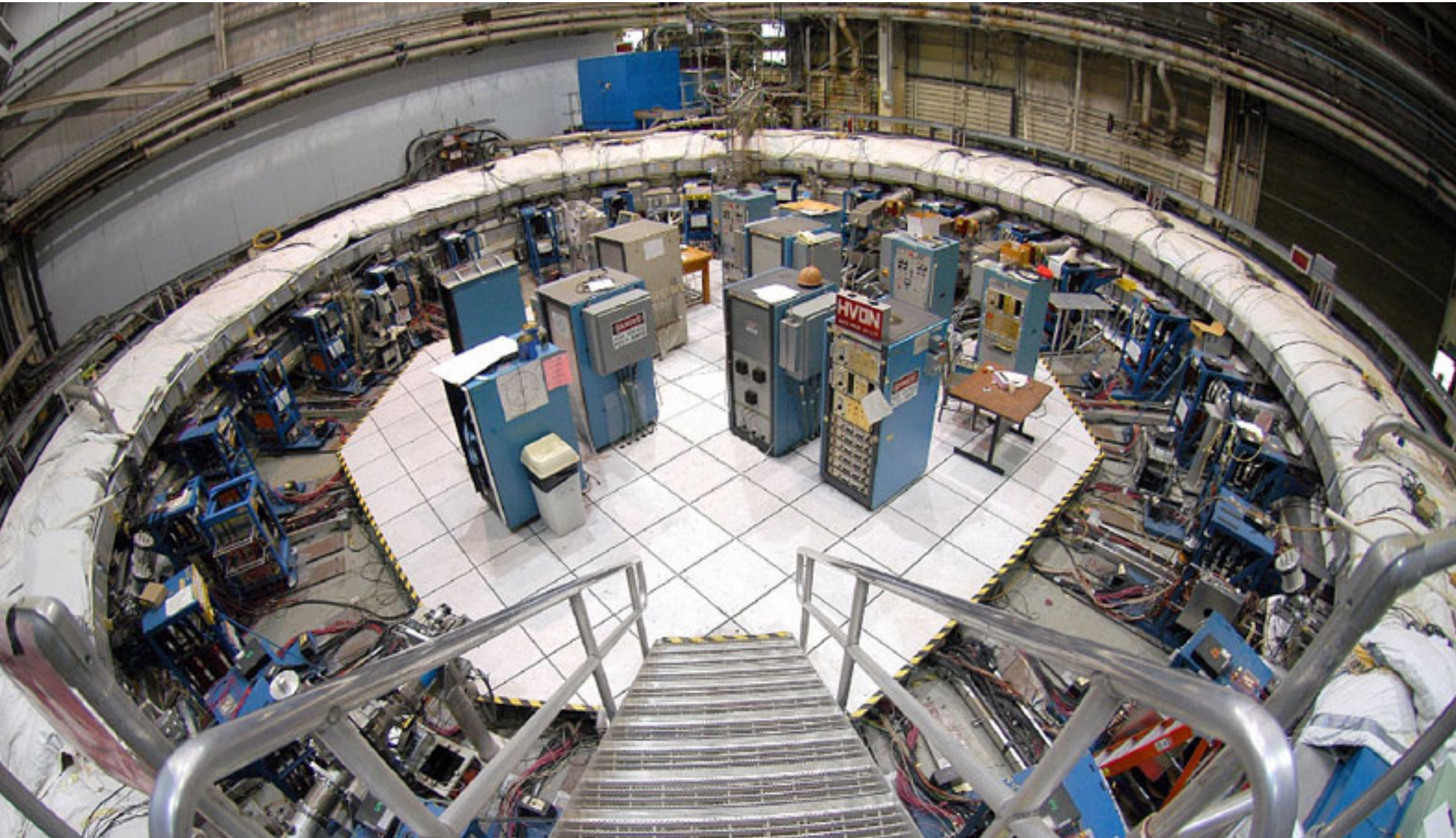
$$a_\mu = \frac{\dfrac{\omega_a}{\omega_p}}{\dfrac{\mu_\mu}{\mu_p} - \dfrac{\omega_a}{\omega_p}}$$



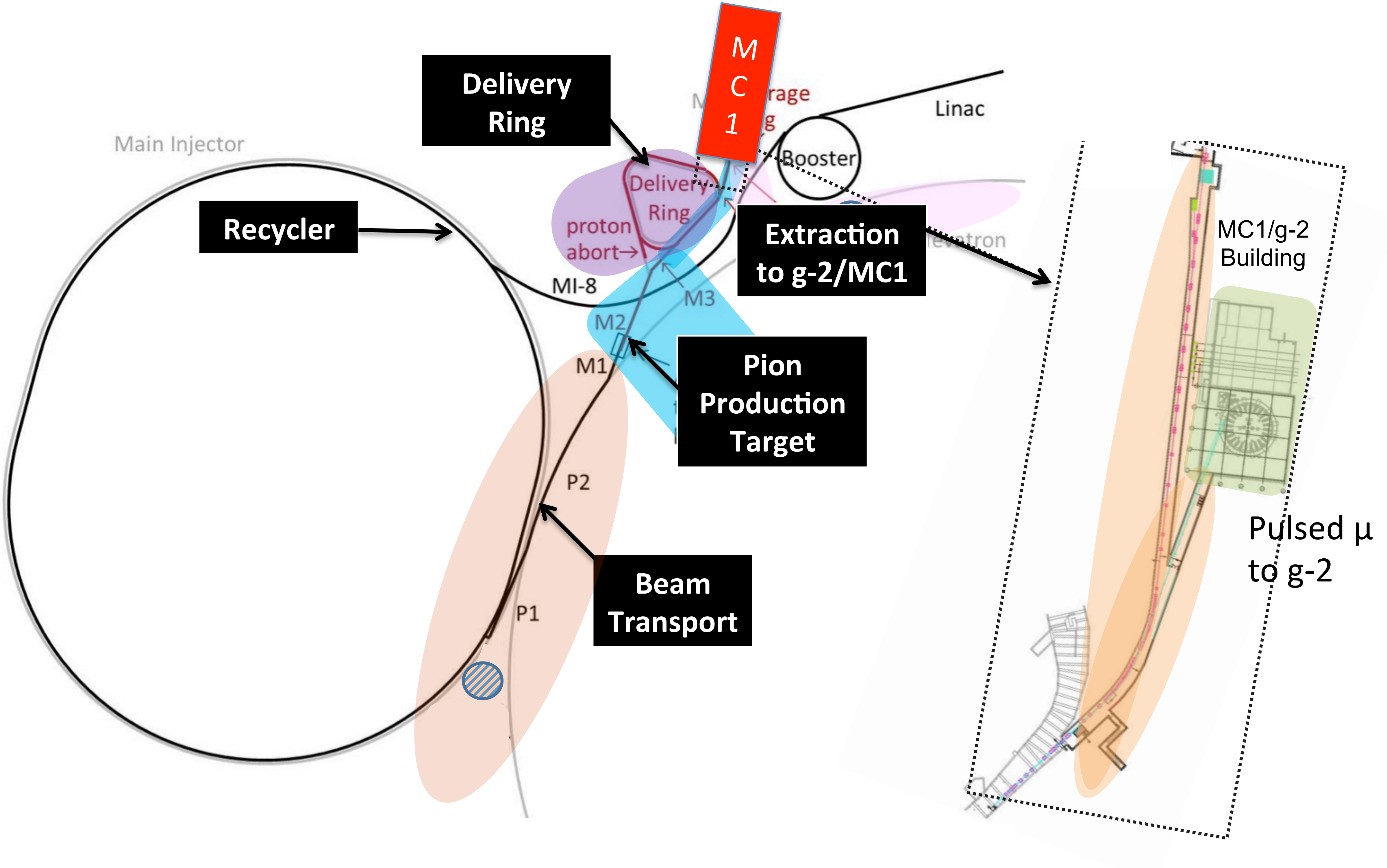
μ_μ/μ_p = 3.183 345 24(37) (120 ppb)
= *3.183 345 39(10)* *(31 ppb)*

External Muonium Hyperfine Expt.

old ring, new instrumentation

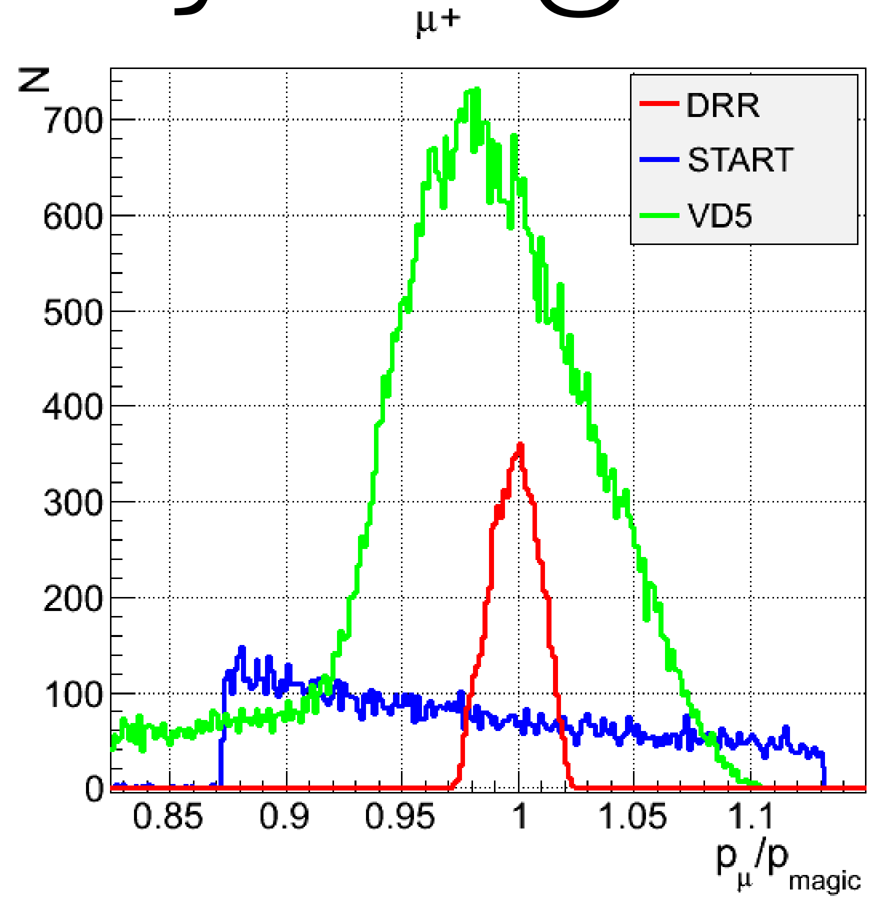


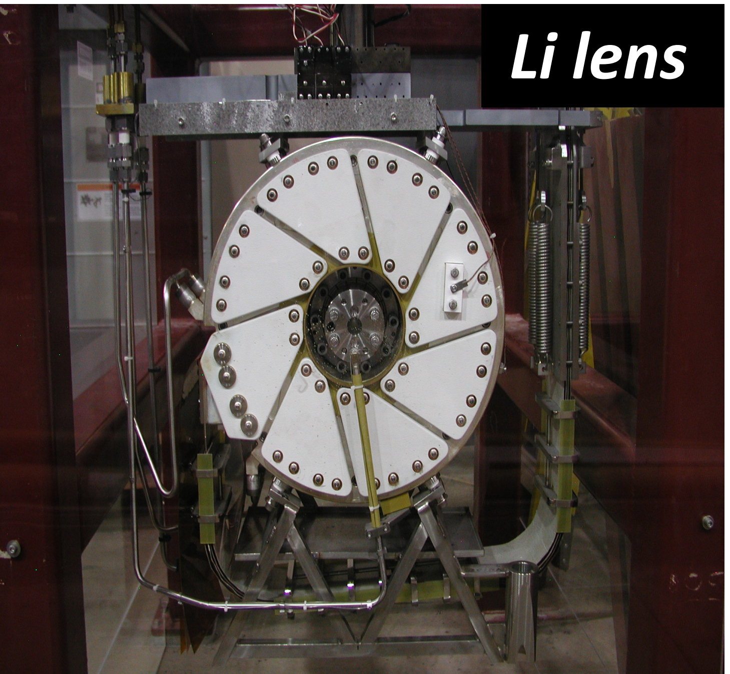
accelerator

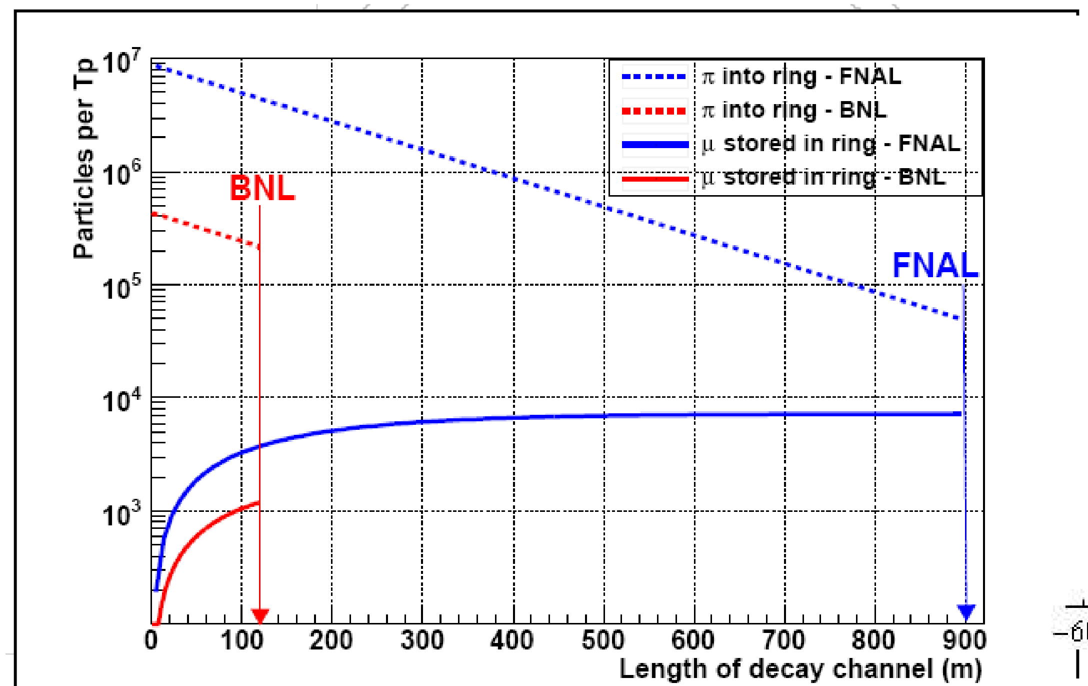


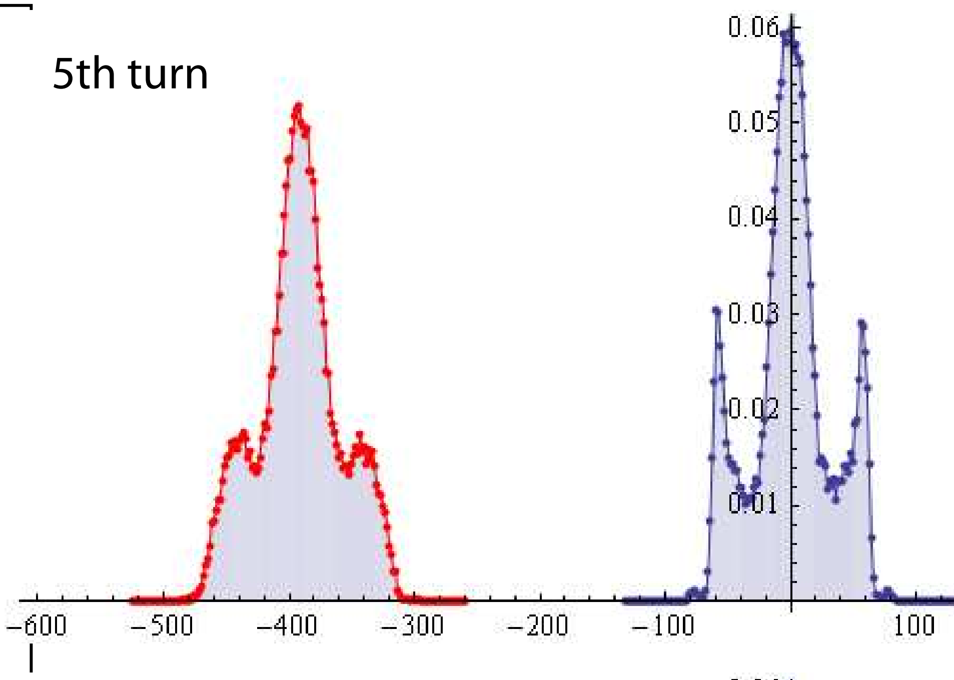
accelerator: delivery ring

- high quality muon beam
  polarization 0.95
- muon momentum spread < 2%
- no protons, no pions





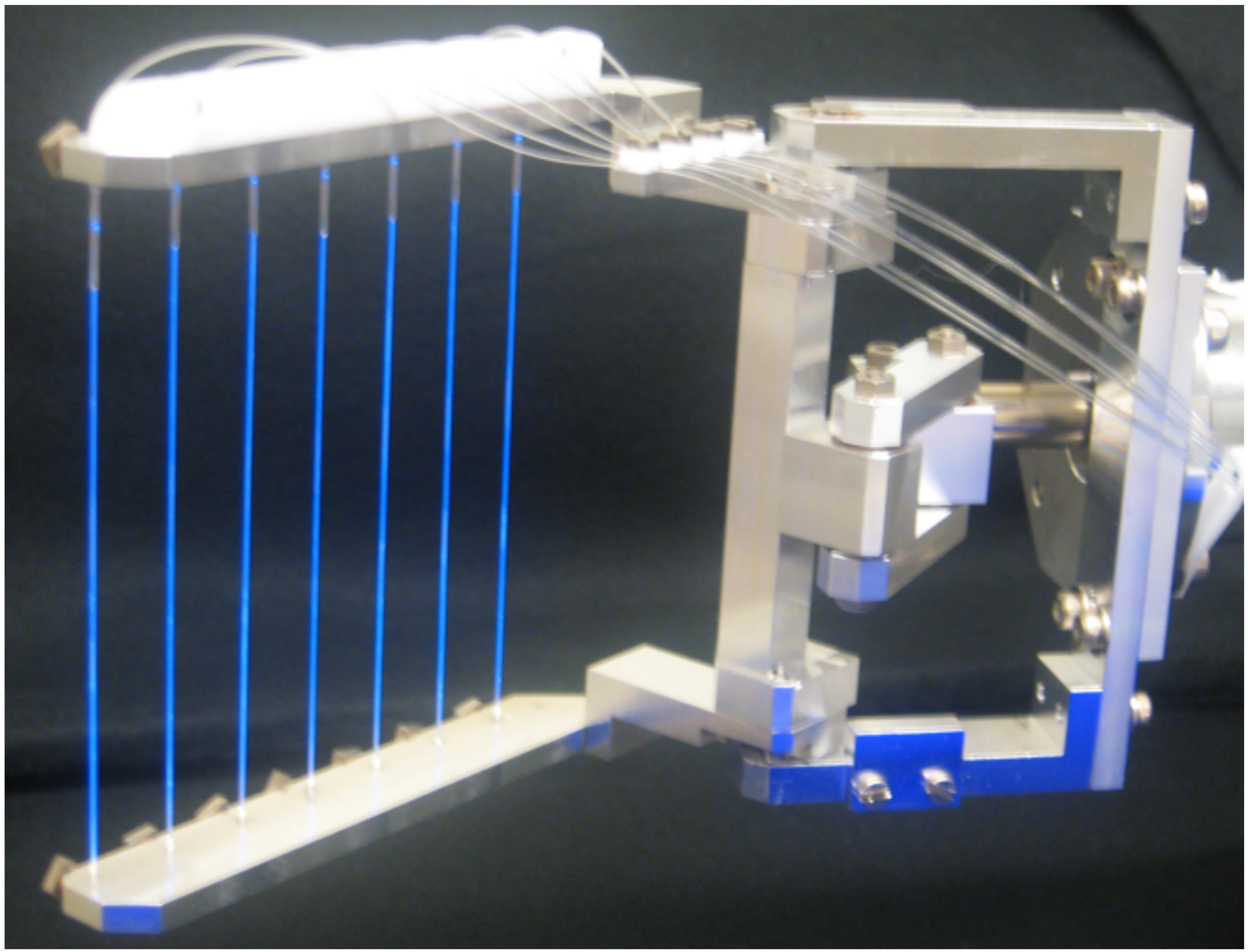




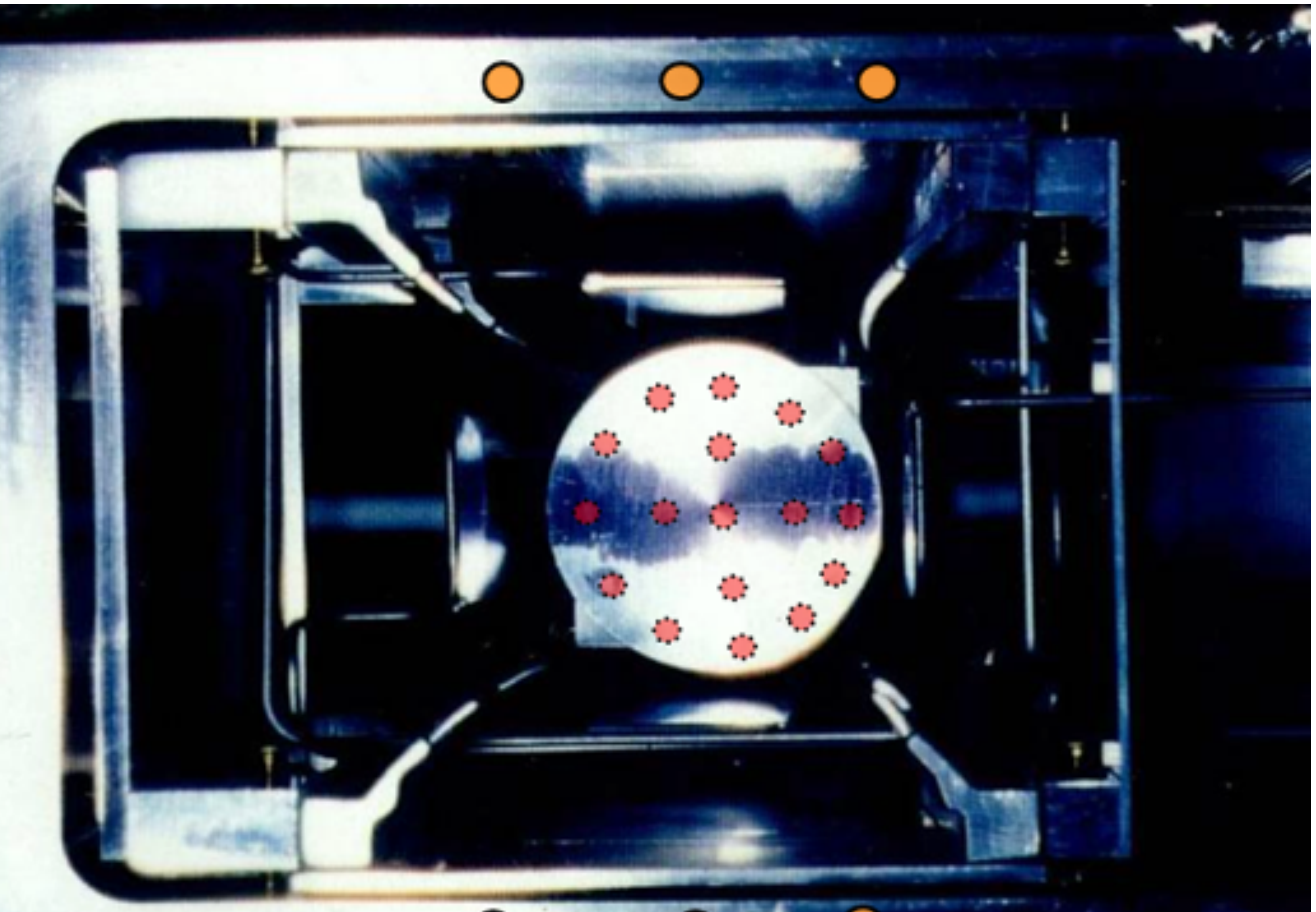
inflector, kicker, scraping

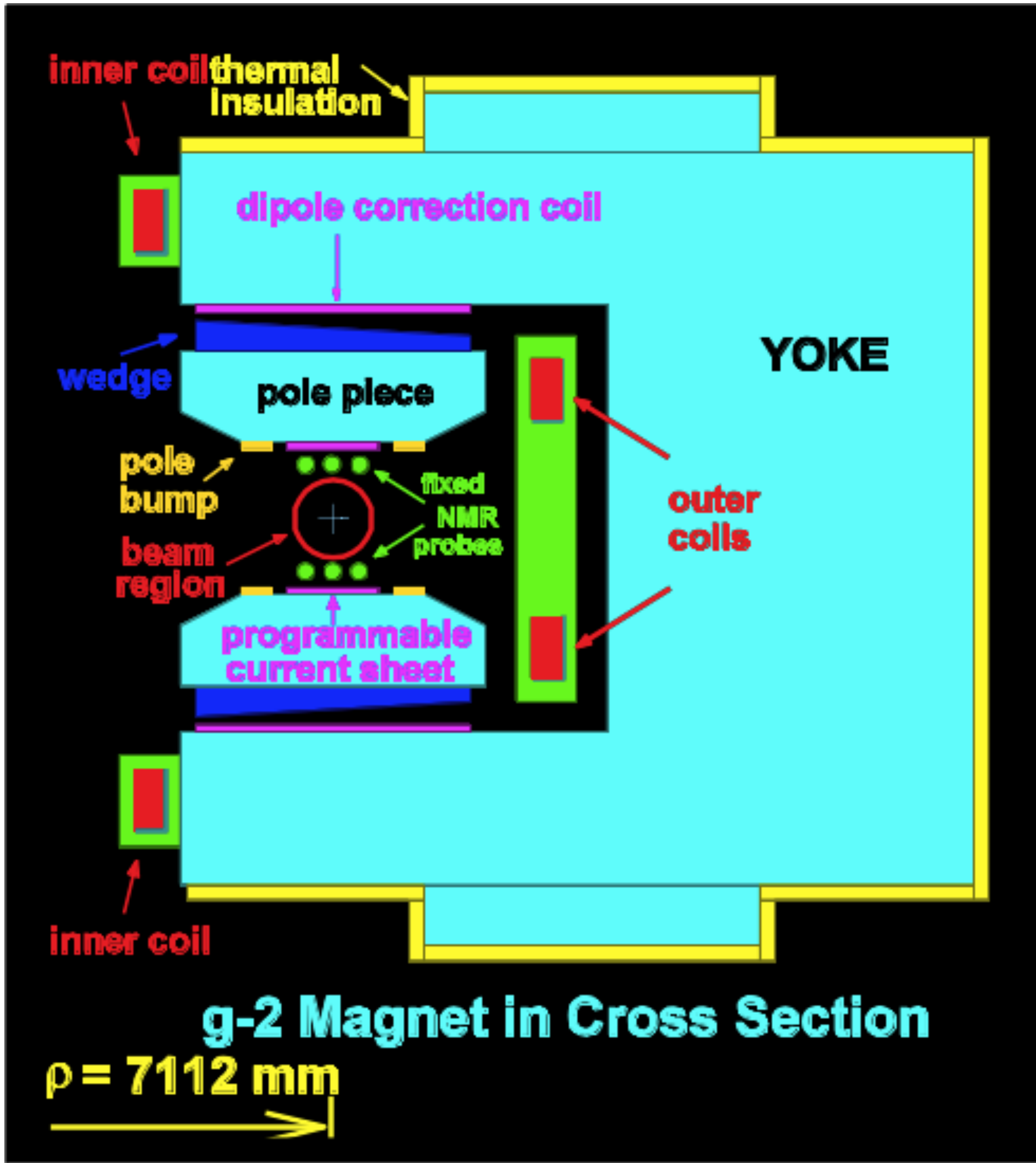
Item	**Factor**	**Value per fill**
Protons on target		10^{12} p
Positive pions captured in FODO, $\delta p/p = \pm 0.5\%$	1.2×10^{-4}	1.2×10^{8}
Muons captured and transmitted to SR, $\delta p/p = \pm 2\%$	0.67%	8.1×10^{5}
Transmission efficiency after commissioning	90%	7.3×10^{5}
Transmission and capture in SR	$(2.5 \pm 0.5)\%$	1.8×10^{4}
Stored muons after scraping	87%	1.6×10^{4}
Stored muons after 30 μs	63%	1.0×10^{4}
Accepted positrons above E = 1.86 GeV	10.7%	1.1×10^{3}
Fills to acquire 1.6×10^{11} events (100 ppb)		1.5×10^{8}
Days of good data accumulation	17 h/d	202 d
Beam-on commissioning days		150 d
Dedicated systematic studies days		50 d
Approximate running time		402 ± 80 d
Approximate total proton on target request		$(3.0 \pm 0.6) \times 10^{20}$

muon beam distribution



NMR probes in a trolley



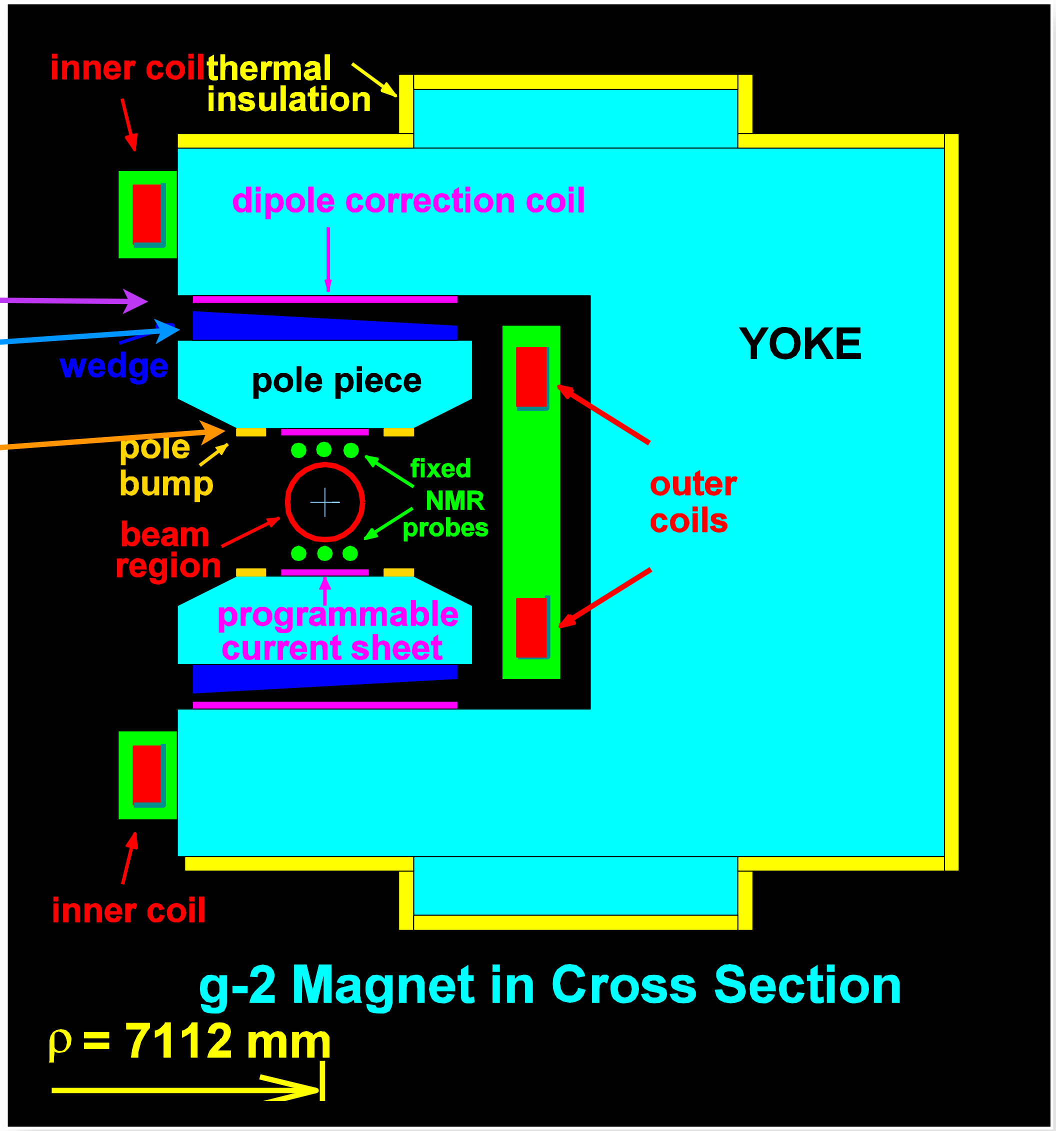


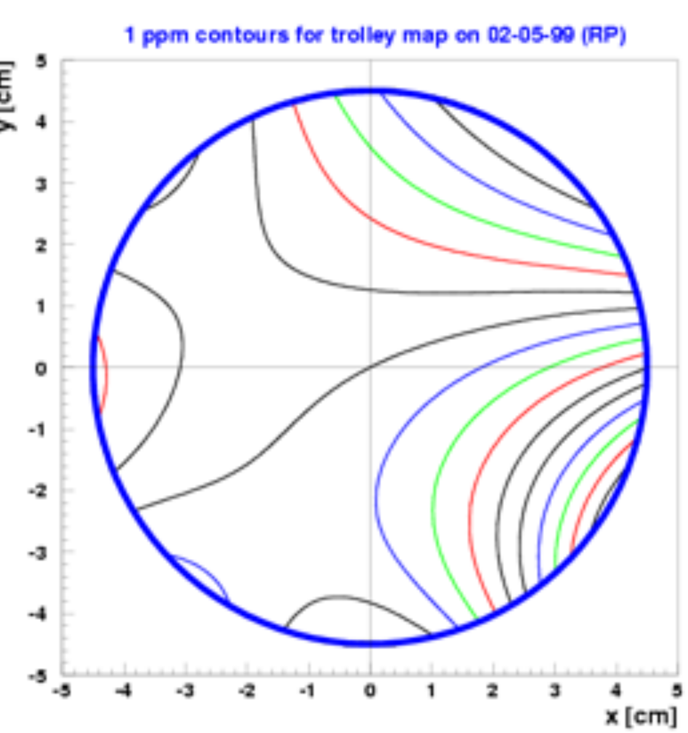
shimming

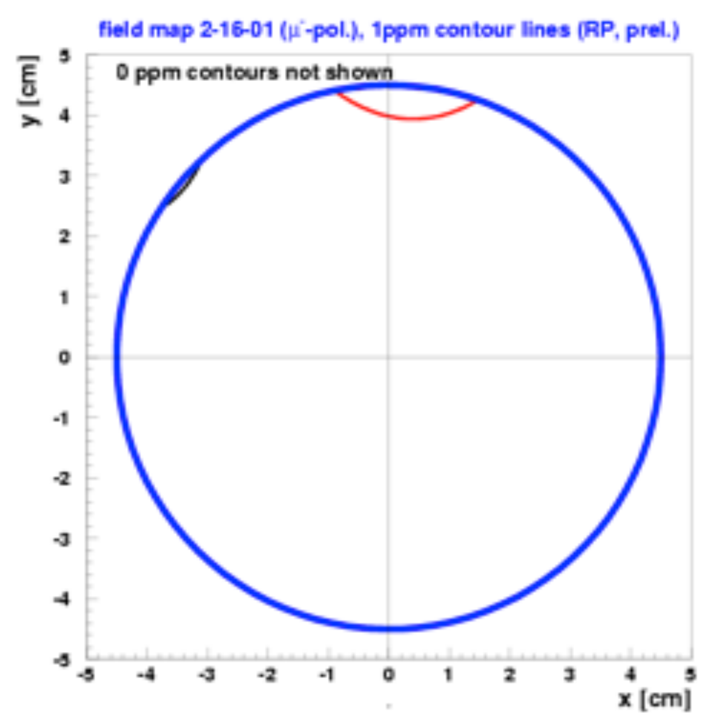
~1 year to shim

independent shimming for

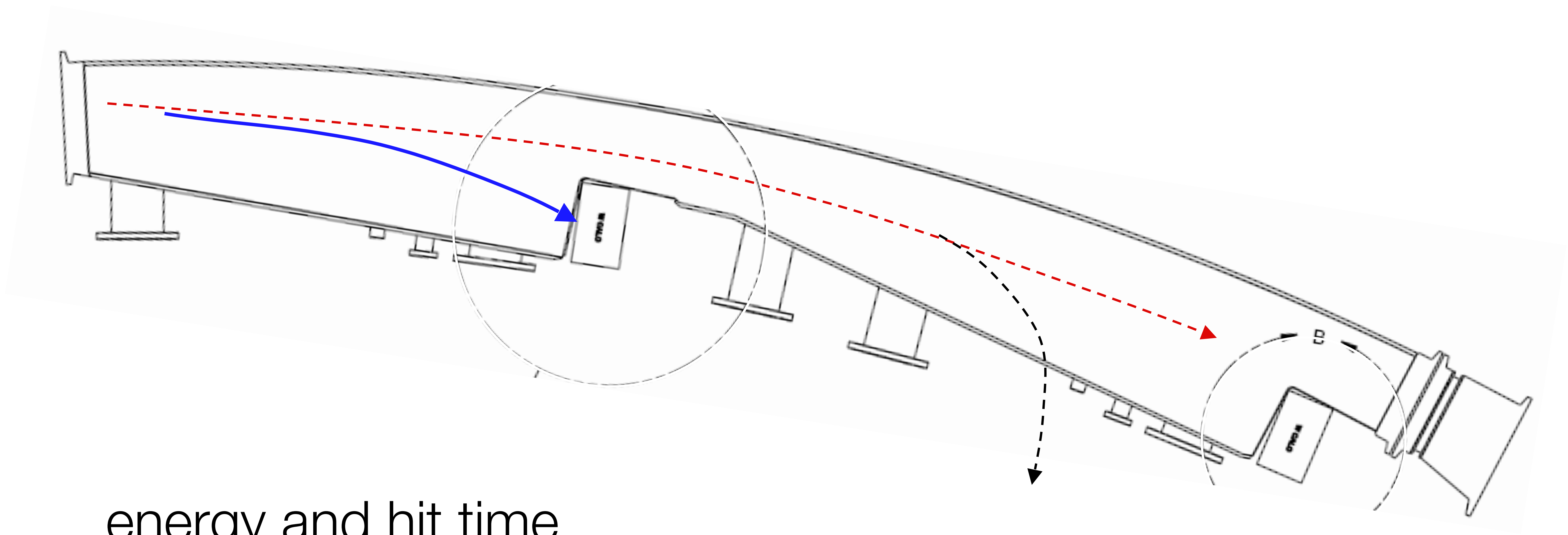
- dipole
- quadrupole
- sextupole





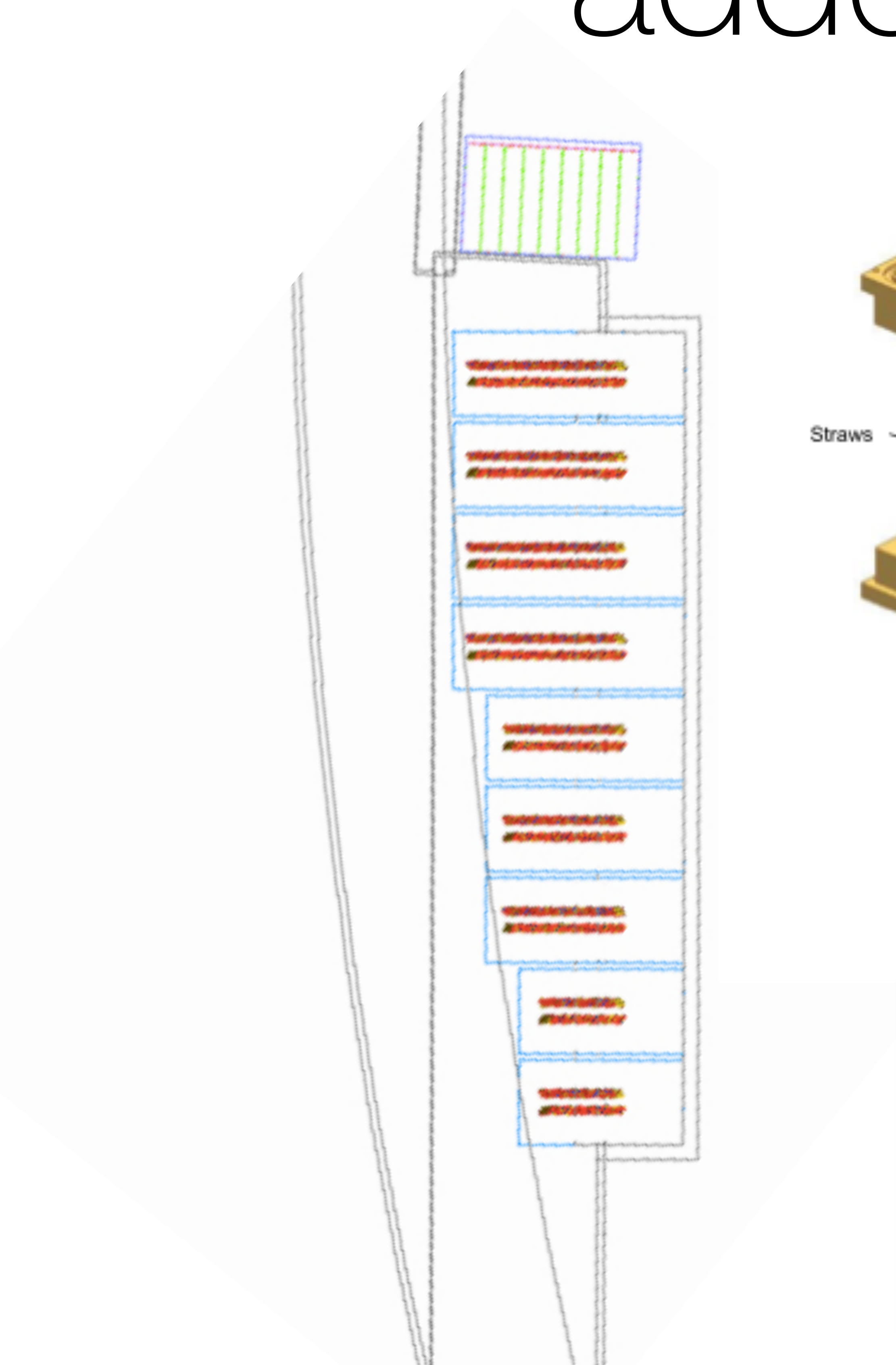


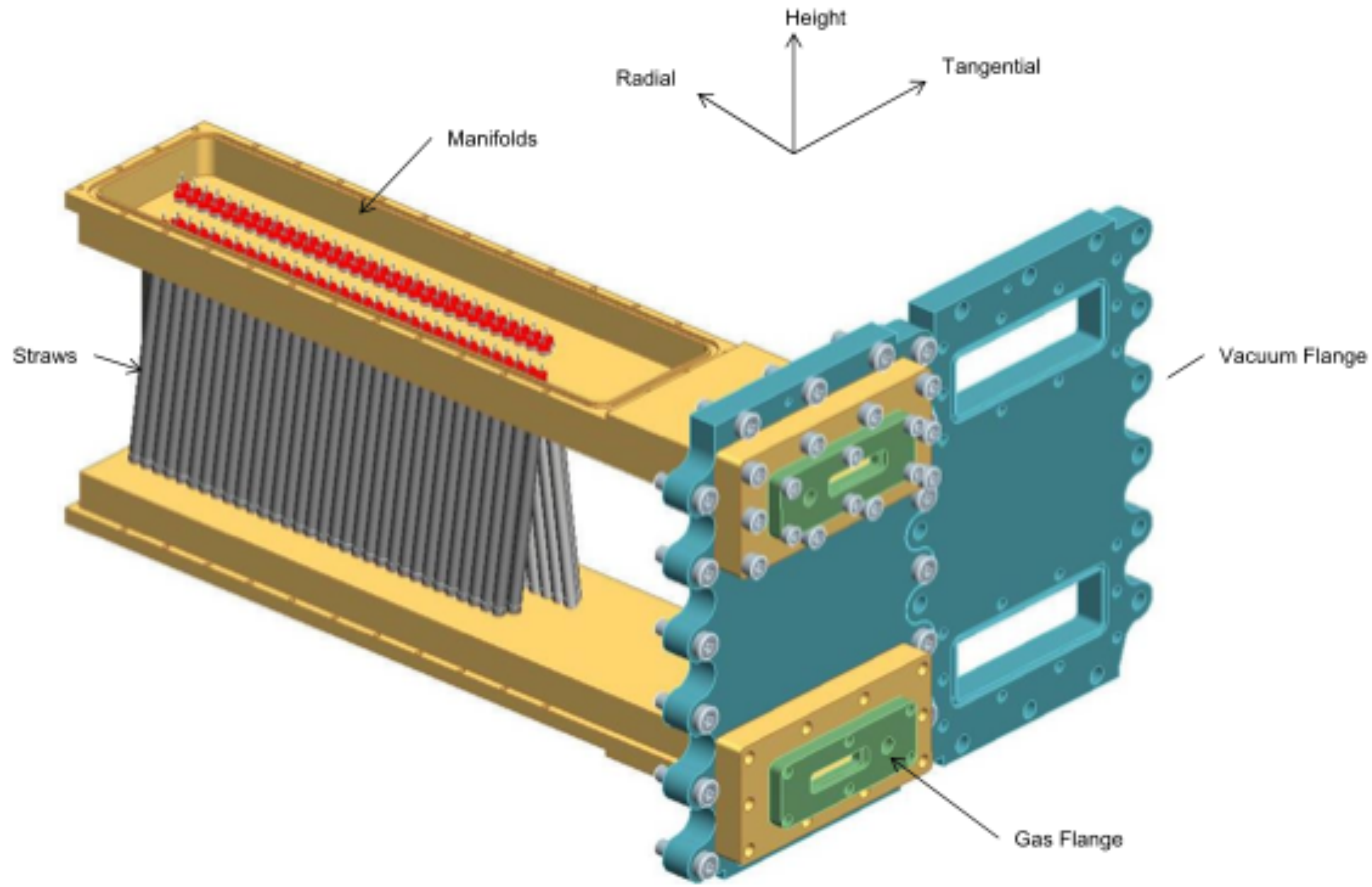
detectors: tracker, calorimeter

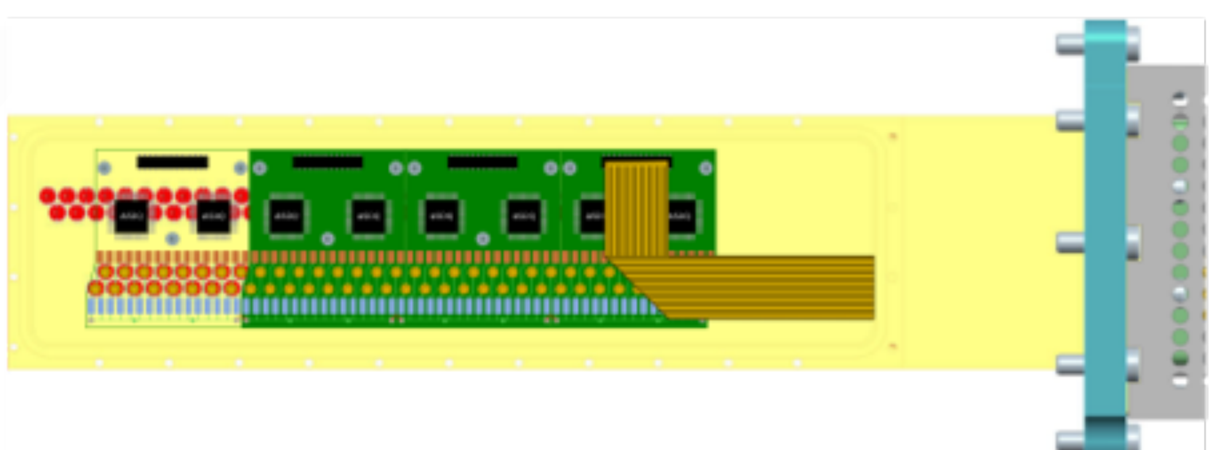


energy and hit time

added tracking

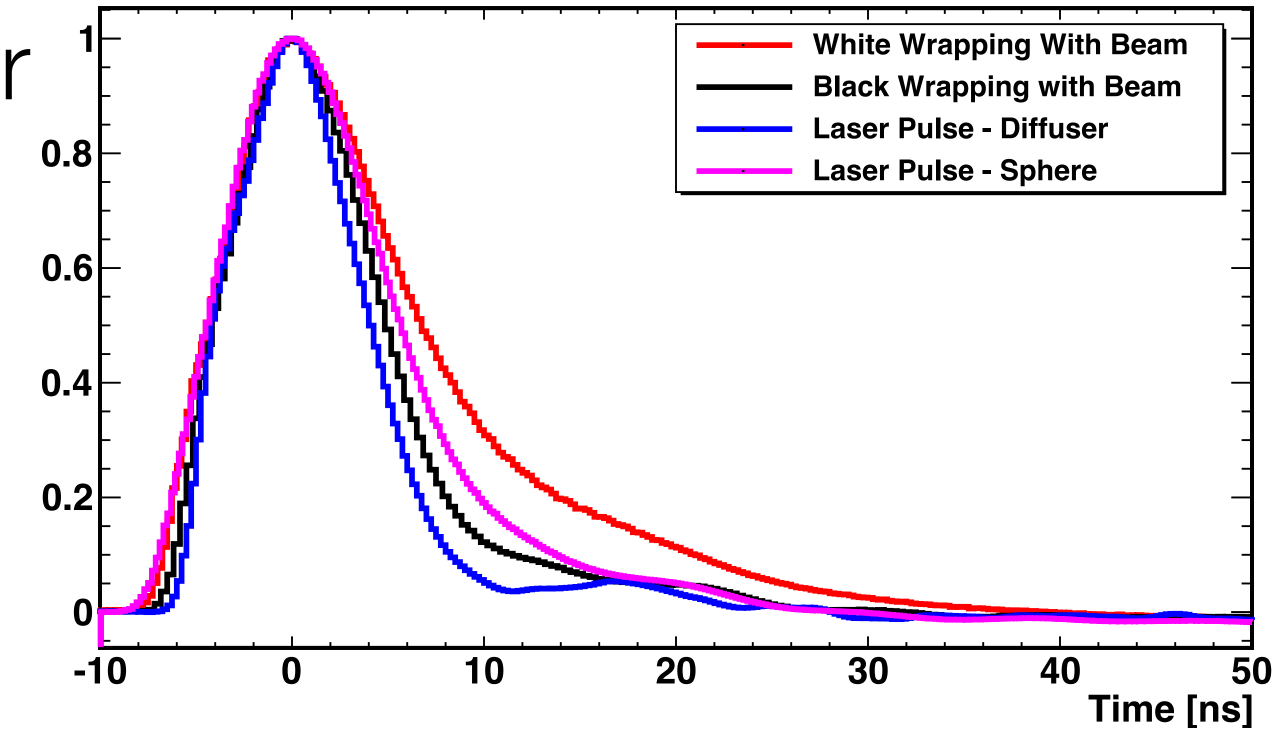


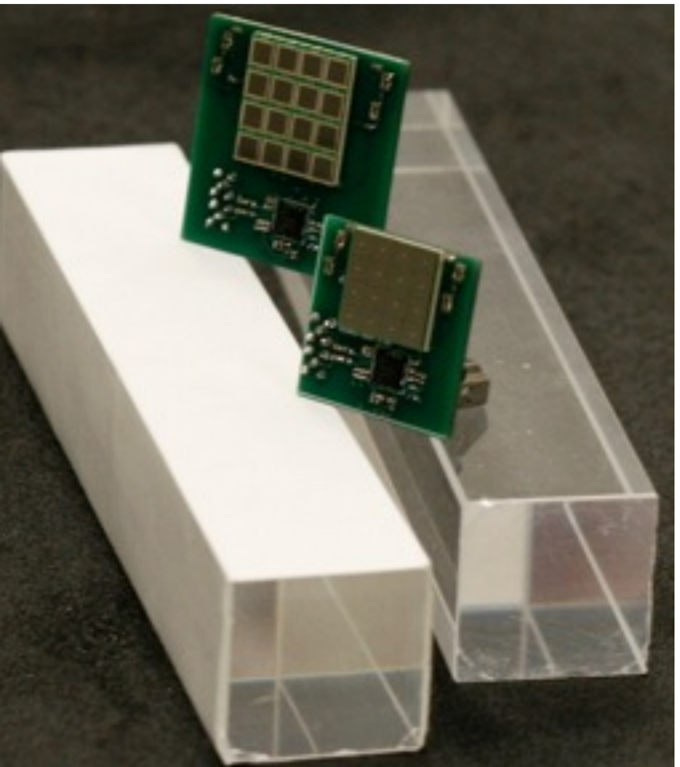




calorimeter

segmented (6x9) PbF2 calorimeter
with SiPM readout (Hamamatsu)
Cerenkov light
PMT-like pulse shape

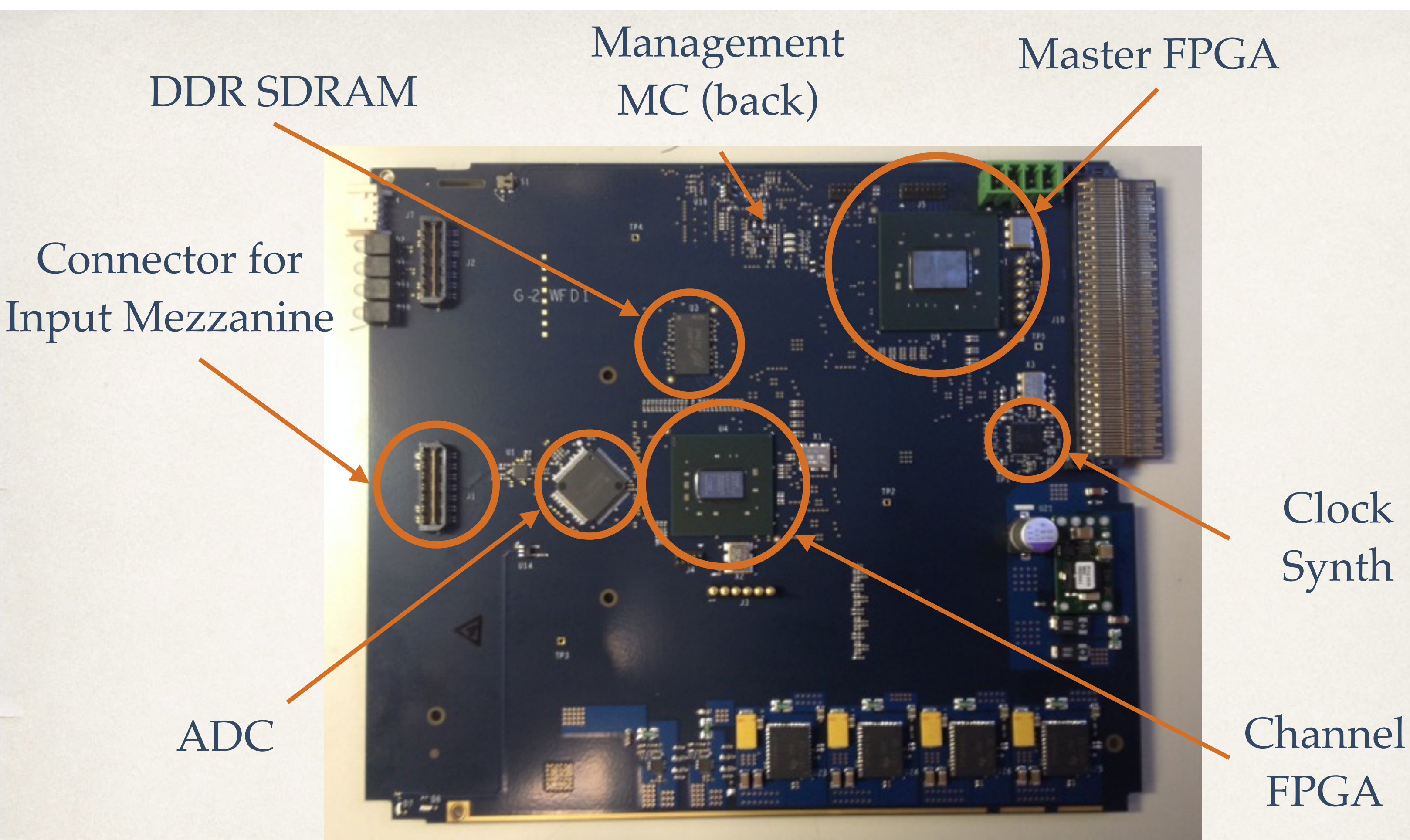




waveform digitizers

800 MHz in uTCA crate

excellent pile-up resolution

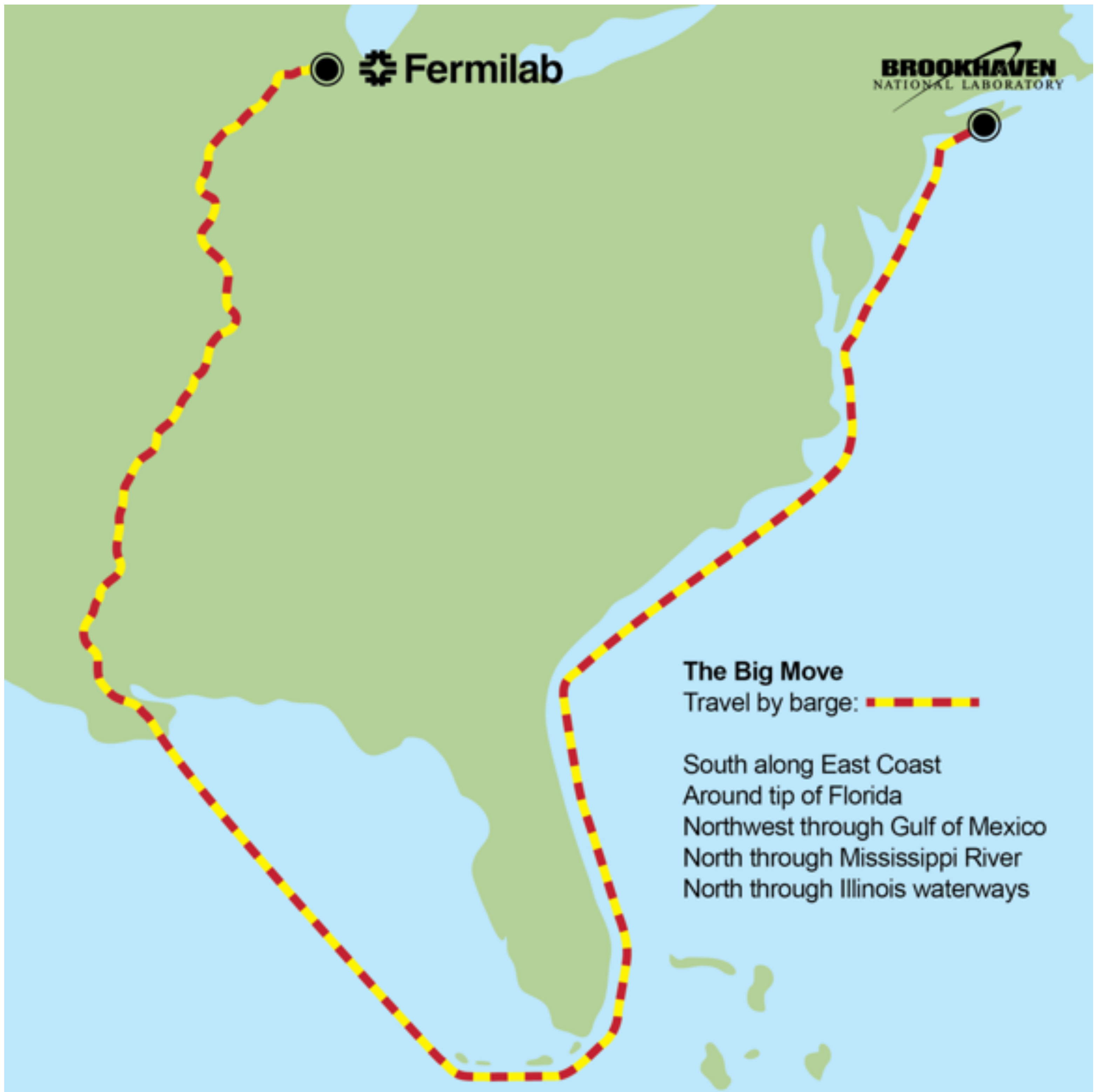


experiment status:

going forward rapidly.

experiment under construction

big move, BNL to Fermilab



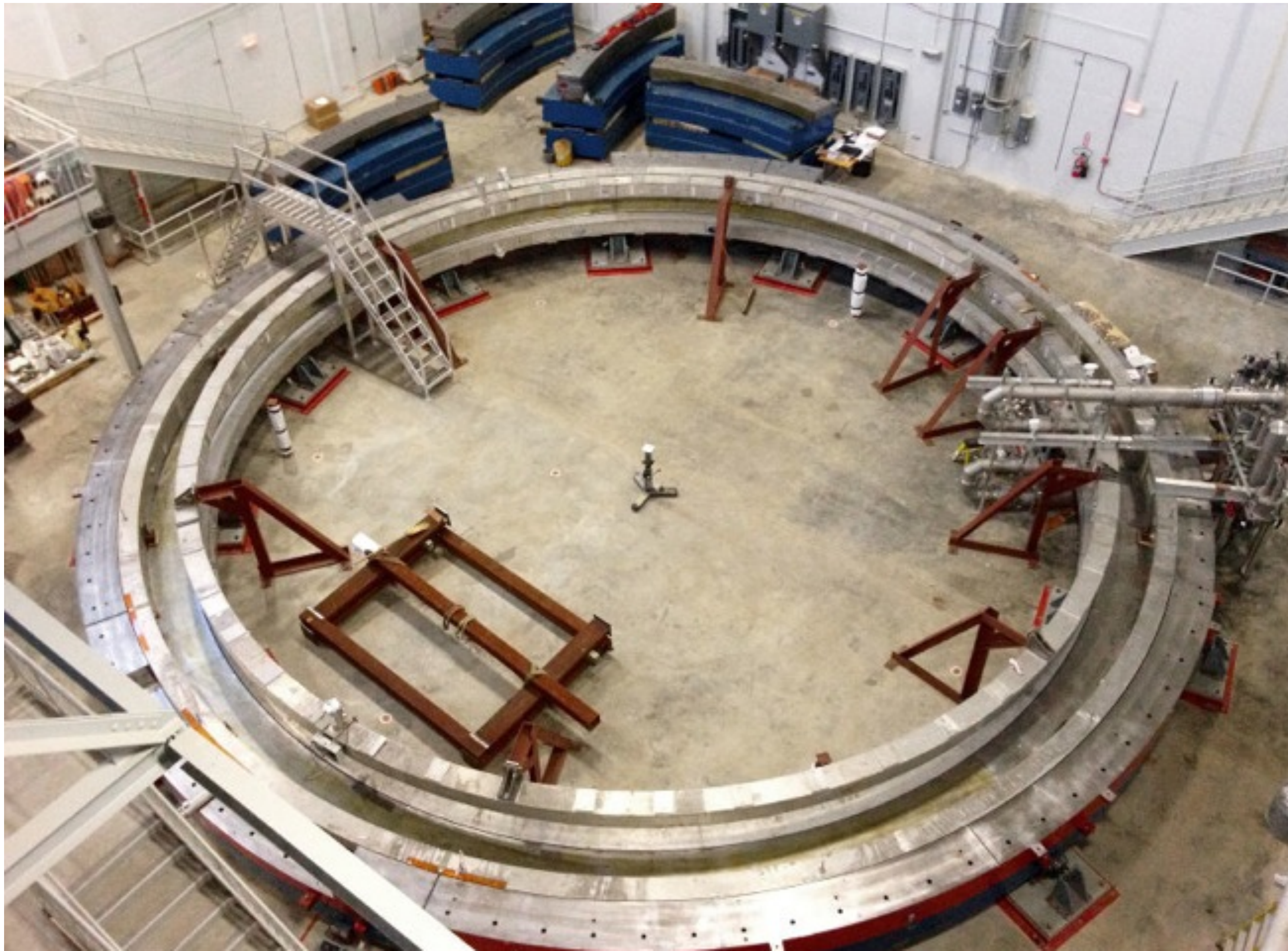
Driving Discovery in Particle Physic
ENERGY
Fermilab
μ
g-2
Muon g-2
http://muon-g-2.fnal.gov
μ
g-2


EMMERT
INTERNATIONAL
Muon g-2
EMMERT


EMMERT

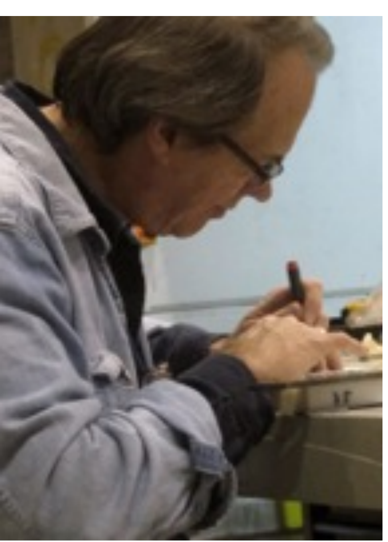
ring re-assembly

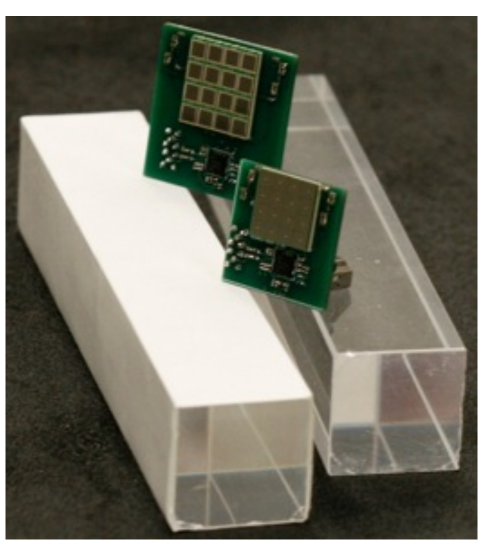
cool-down & ramp-up in Spring 2015

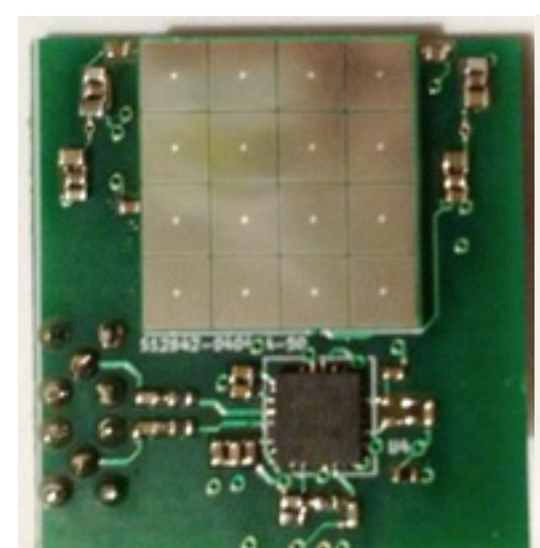


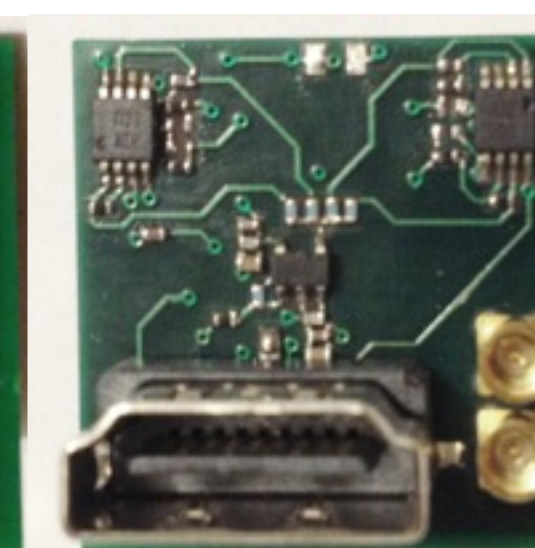
calorimeter at SLAC

- ☑ energy resolution
- ☑ timing resolution
- ☑ energy scale linearity
- ☑ energy scale stability
- ☑ PMT-like pulse shape



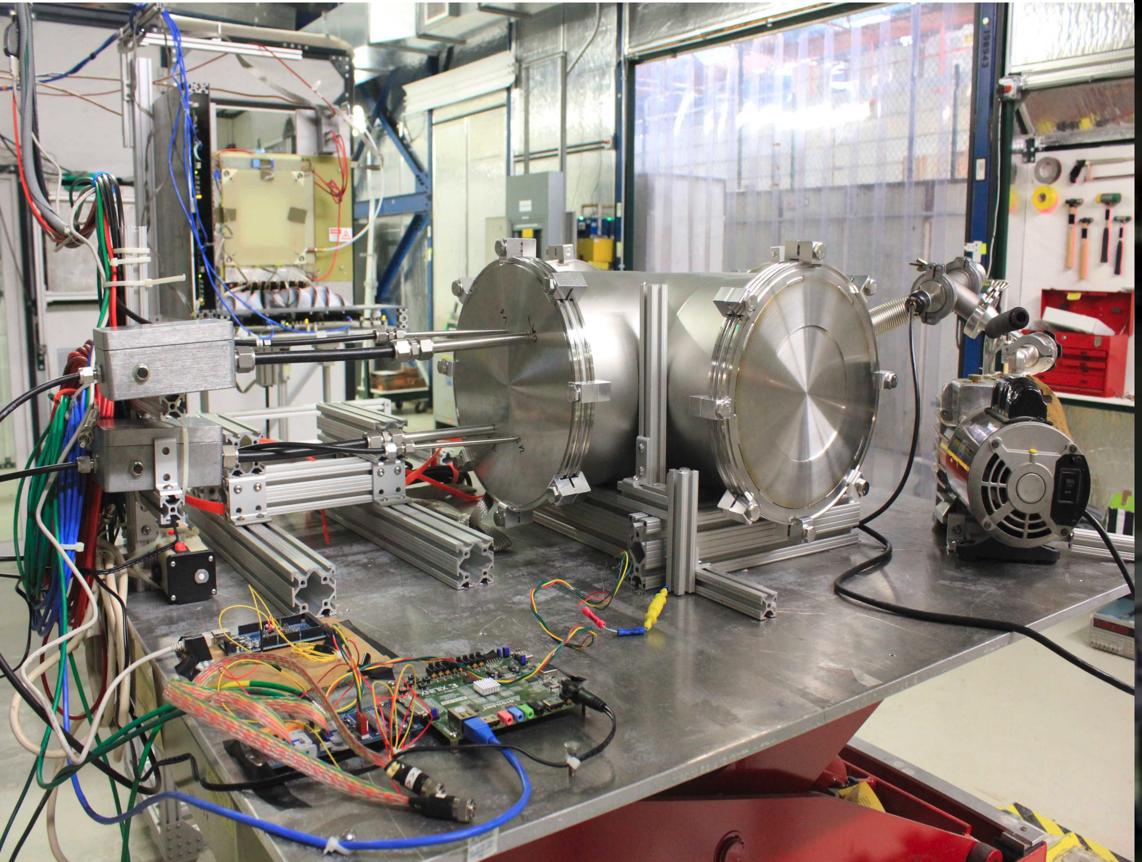


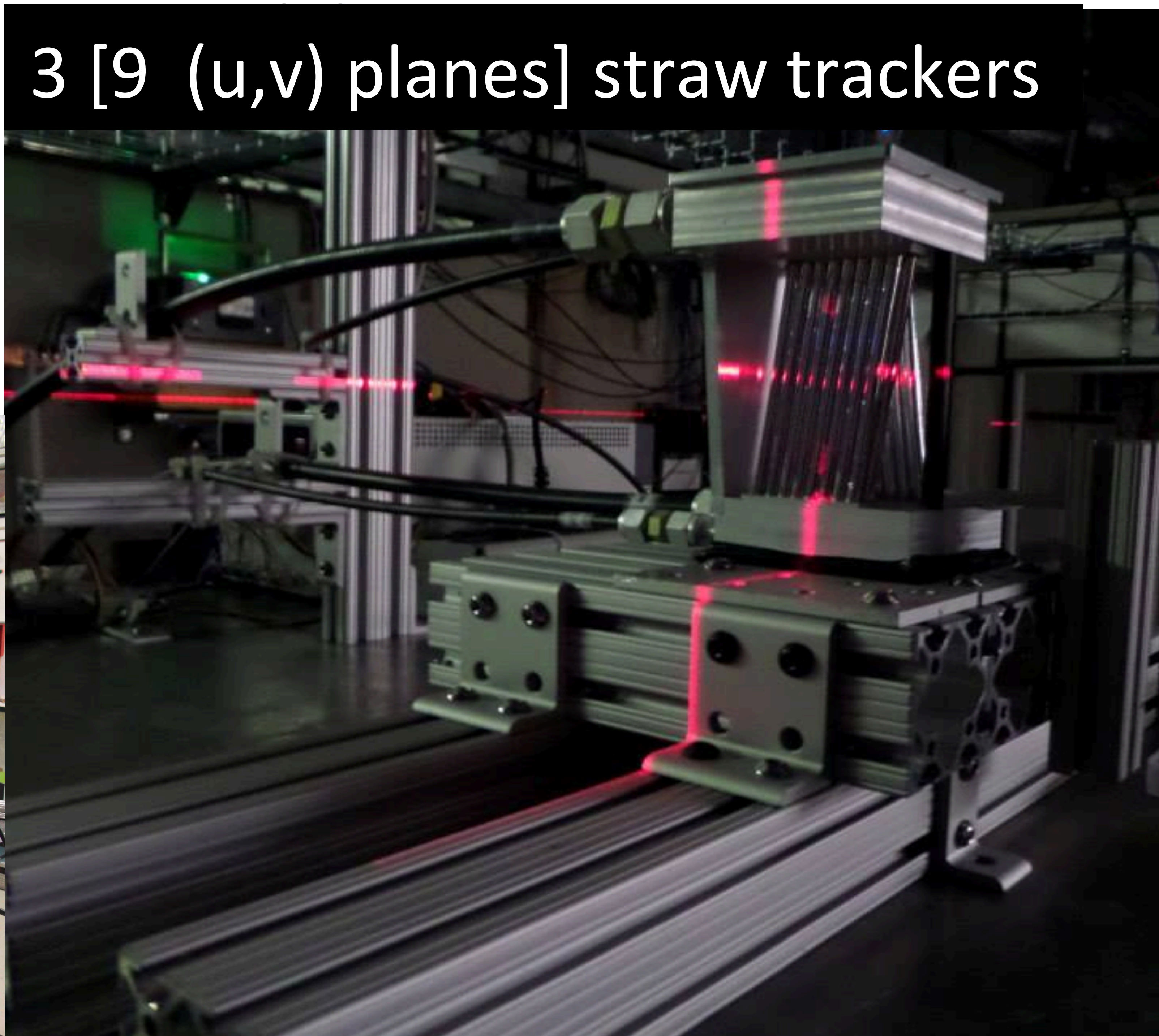


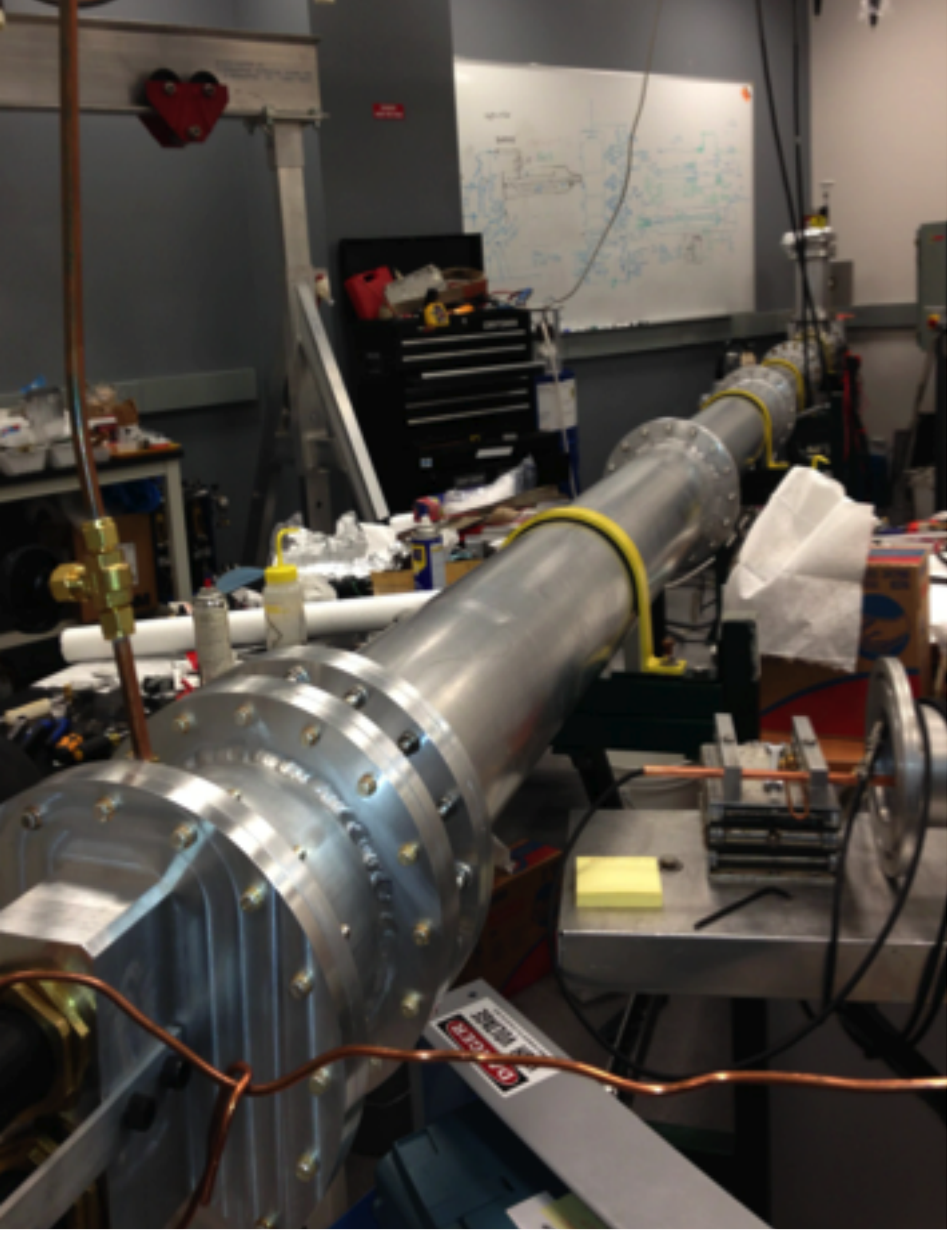


tracker at Fermilab

- ☑ working prototype
- ☑ drift time
- ☑ track reconstruction



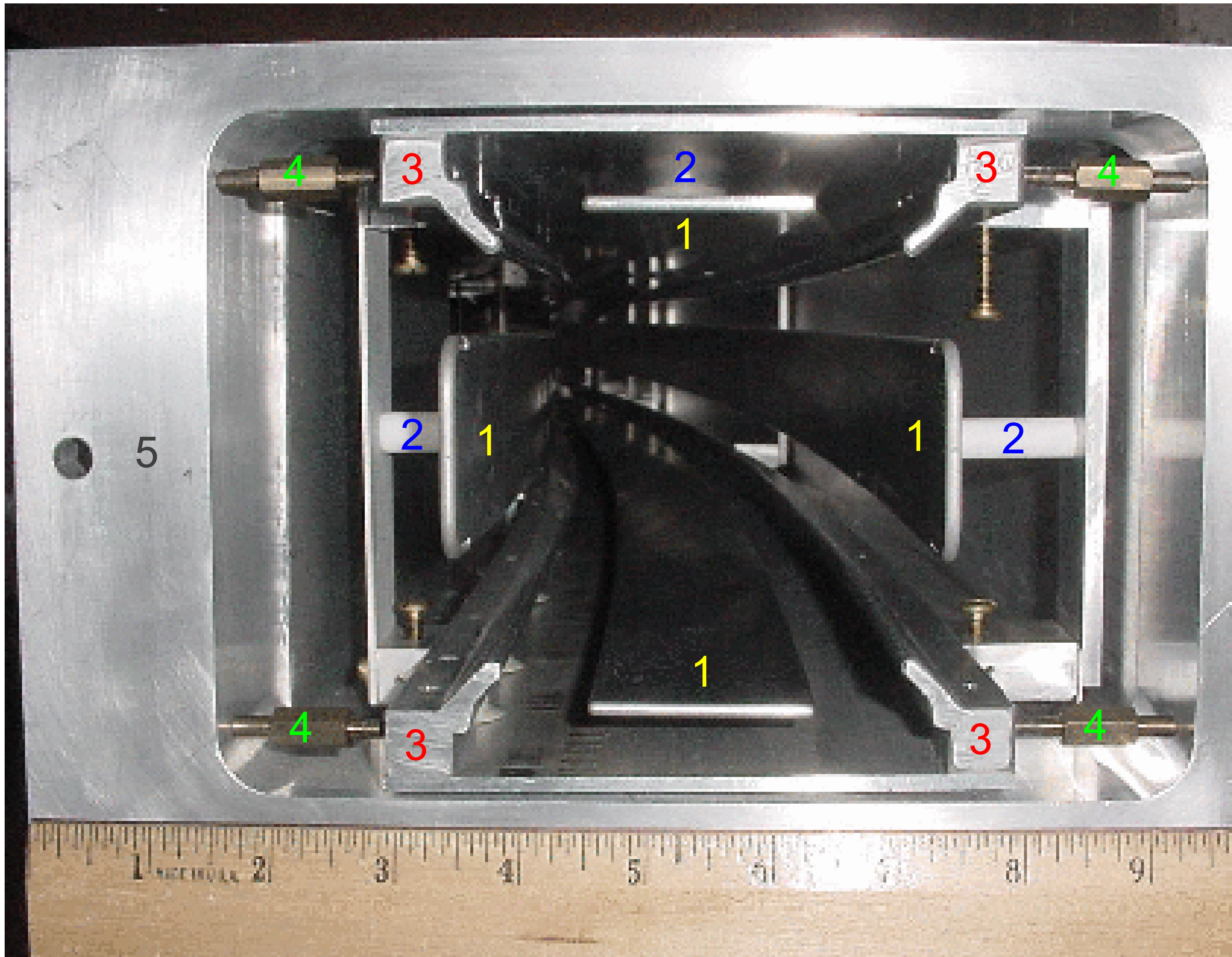




kicker at Cornell

☑ triaxial Blumlein line

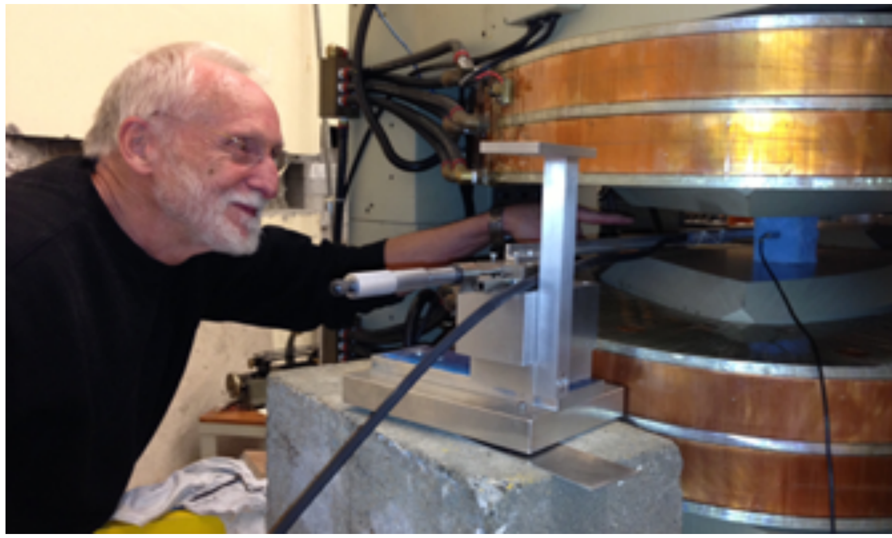
☑ new kicker electrode geometry



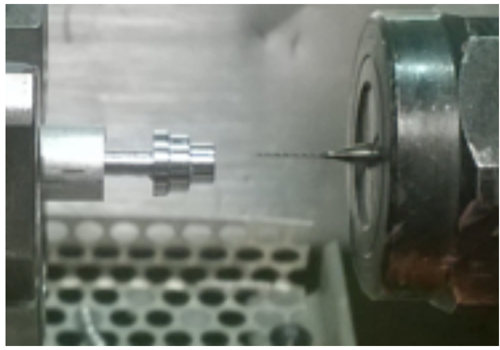
quads at BNL

☑ increased HV (higher tune)

NMR probes at UW



- ☑ frequency resolution
- ☑ frequency stability (temp, …)
- ☑ zero crossings (E821) → digitization



trolley at ANL

- ☑ position reproducibility

and many others …

$g - 2$ summary

- precision measurement of $g - 2$
- **4 times better** than the previous BNL experiment
  0.54 ppm -> **0.14 ppm**
- test of Standard Model, sensitive to New Physics
- ***taking data in early 2017***